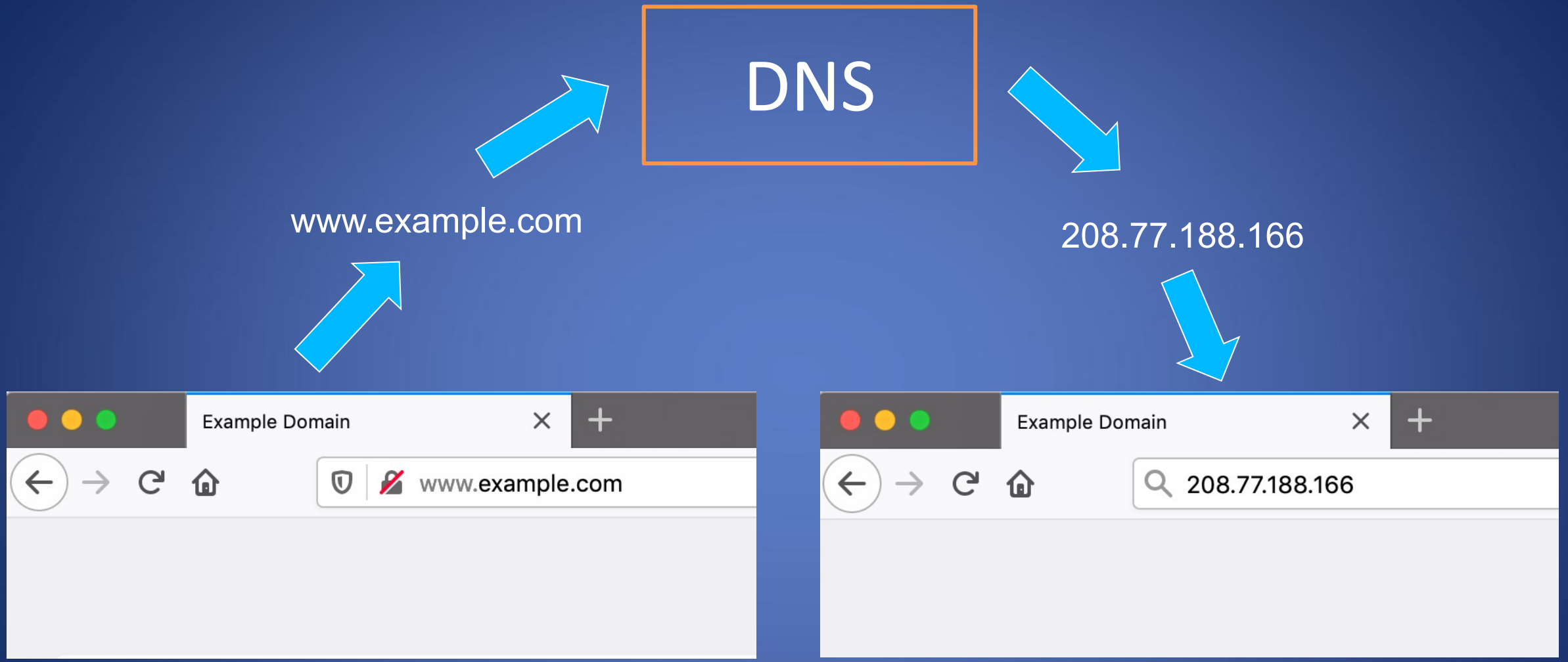
Network III
DoS, DNS, TLS

CS 1660: Introduction to Computer Systems Security

DNS Domain Name System


DNS
www.example.com
208.77.188.166
Example Domain
www.example.com
Example Domain
208.77.188.166

Domain Name System

- The domain name system (DNS) is an application-layer protocol
- Basic function of DNS
  - Map domain names to IP addresses
  - The mapping is many to many
- Examples:
  - www.cs.brown.edu and cs.brown.edu map to 128.148.32.12
  - google.com maps to 198.7.237.251, 198.7.237.249, and other addresses

- More generally, DNS is a distributed database that stores resource records
  - Address (A) record: IP address associated with a host name
  - Mail exchange (MX) record: mail server of a domain
  - Name server (NS) record: authoritative server for a domain

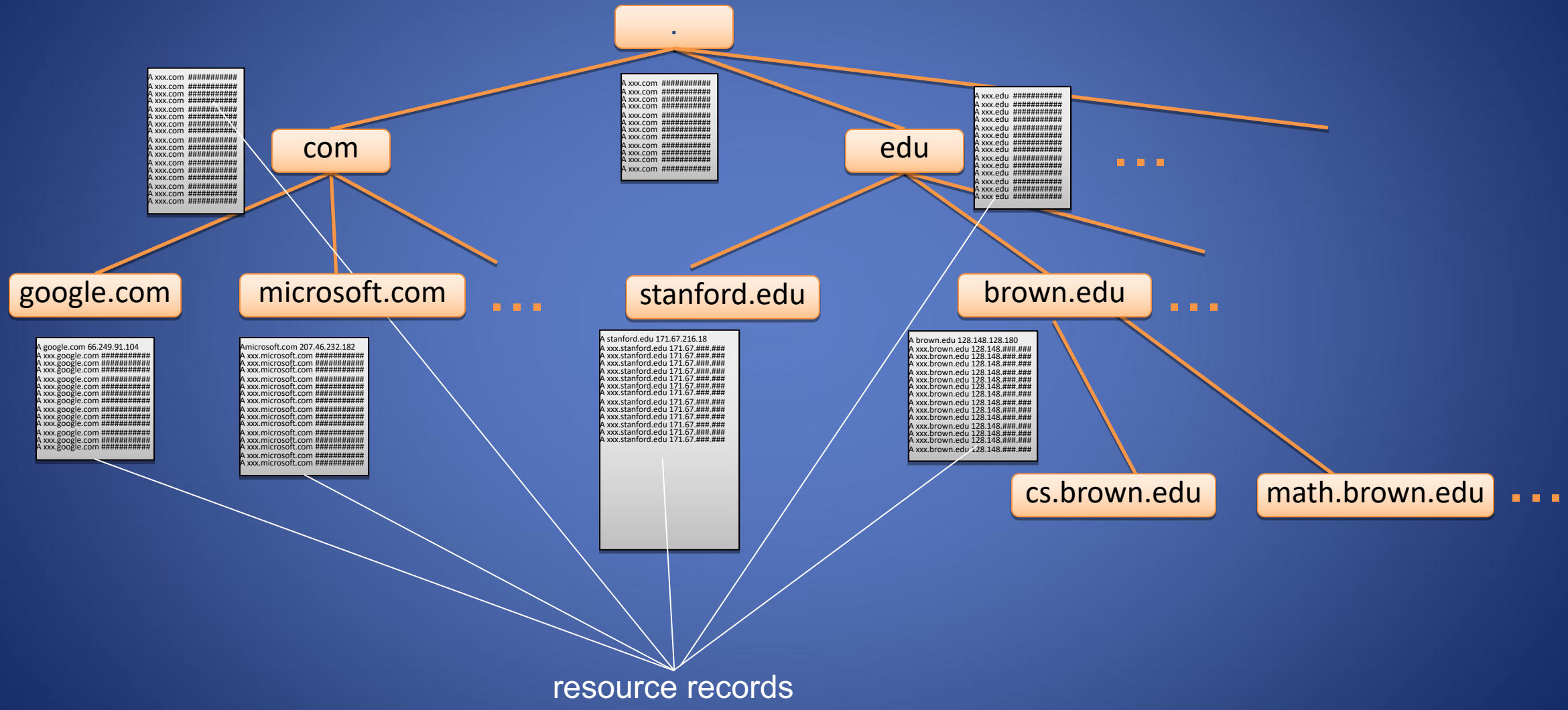
Domains

- FQDN (Fully Qualified Domain Name)
  - [Host name].[Domain].[TLD].[Root]
  - Two or more labels, separated by dots (e.g., cs.brown.edu)
- Root name server
  - It is a "." at the end of the FQDN
- Top-level domain (TLD)
  - Generic (gTLD), e.g., .com, .org, .net
  - Country-code (ccTLD), e.g., .ca, .it

- ICANN (Internet Corporation for Assigned Names and Numbers)

  "One World. One Internet."
  - Keeps database of registered gTLDs (InterNIC)
  - Accredits registrars for gTLDs
- gTLDs
  - Managed by ICANN
- ccTLDs
  - Managed by government organizations

DNS Tree


.
com
edu
google.com
microsoft.com
stanford.edu
brown.edu
cs.brown.edu
math.brown.edu
resource records

Name Servers

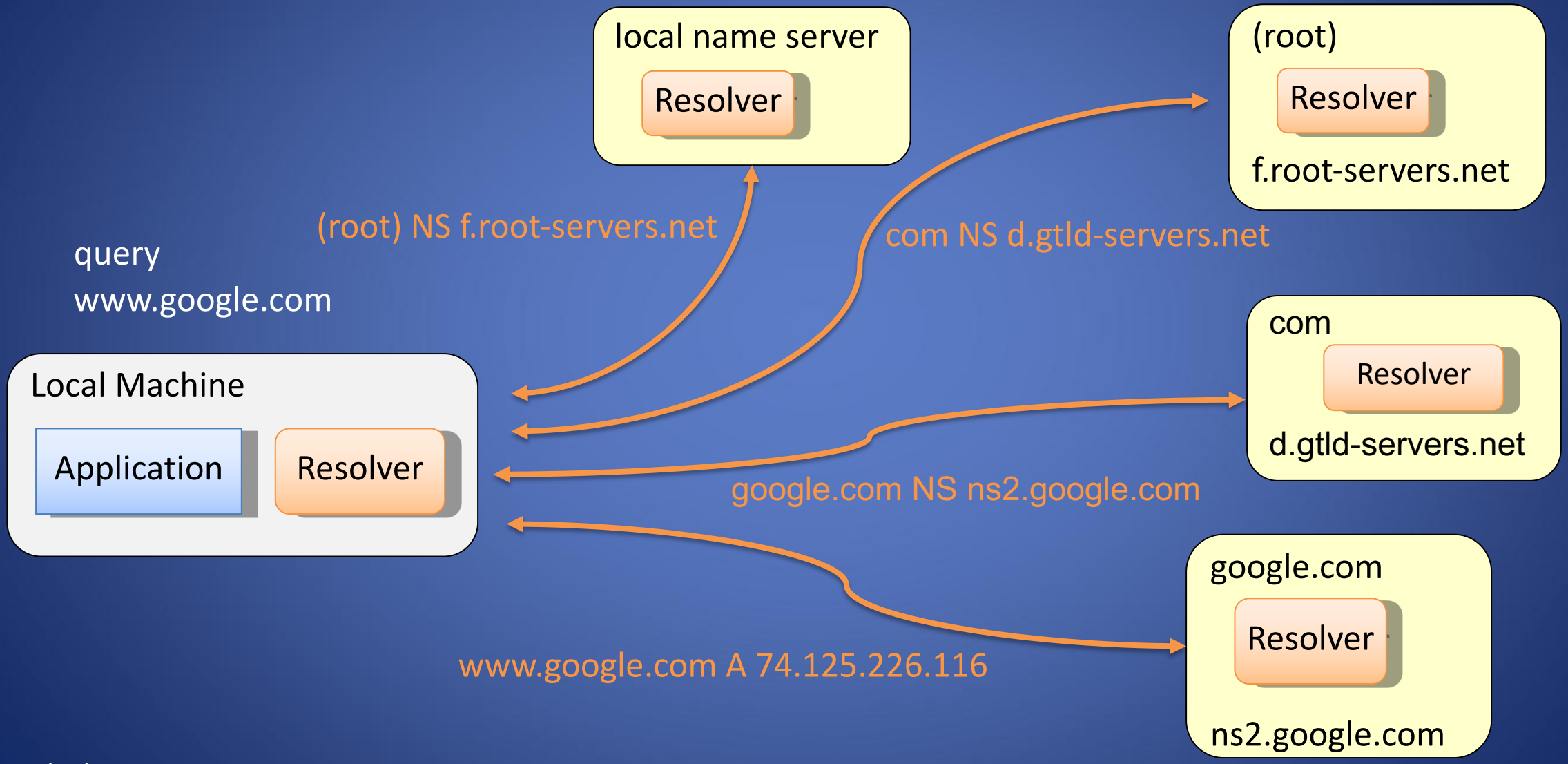
- Name server
  - Keeps local database of DNS records
  - Answers DNS queries
  - Can ask other name servers if record not in local database
- Authoritative name server
  - Stores reference version of DNS records for a zone (partial tree)
- Examples
  - dns.cs.brown.edu is authoritative for cs.brown.edu
  - bru-ns2.brown.edu is authoritative for brown.edu
- Root servers
  - Authoritative for the root zone (TLDs)
  - [a-m].root-servers.net (ICANN)
- Command tools for checking DNS
  - dig, nslookup, host
    (similar results with some differences)

Name Resolution

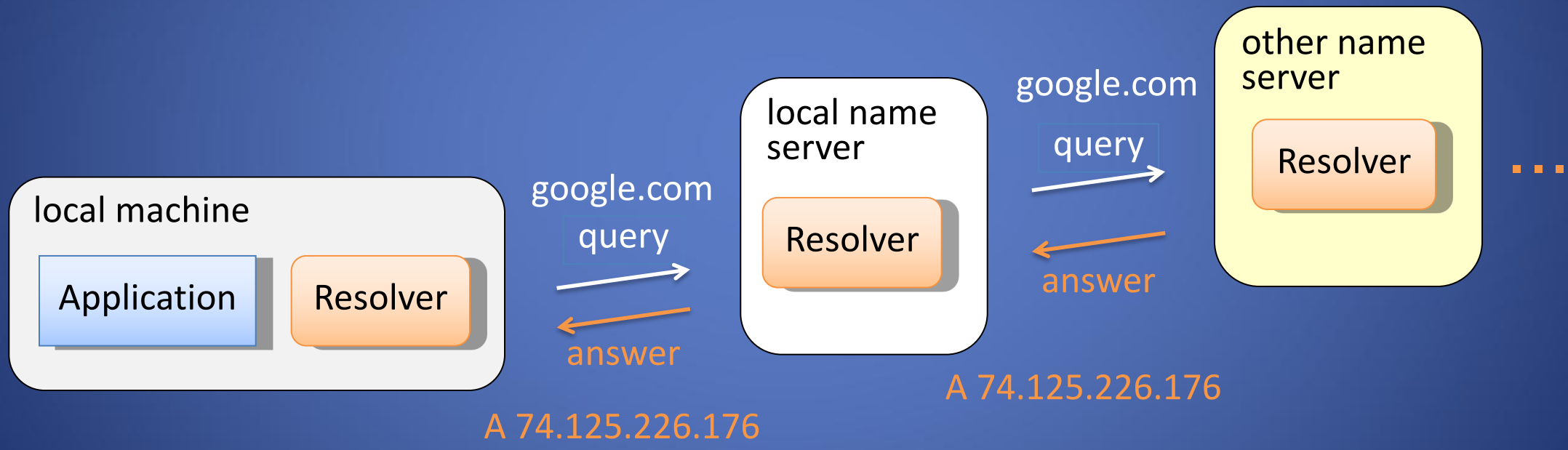
Name Resolution

- Resolver
  - Program that retrieves DNS records
  - Caches records received
  - Connects to a name server (default, root, or given)
- Iterative resolution
  - Name server refers client to authoritative server (e.g., a TLD server) via an NS record
  - Repeat
- Recursive resolution
  - Name server queries another server and forwards the final answer (e.g., A record) to client

Iterative Name Resolution



Recursive Name Resolution



Glue Records

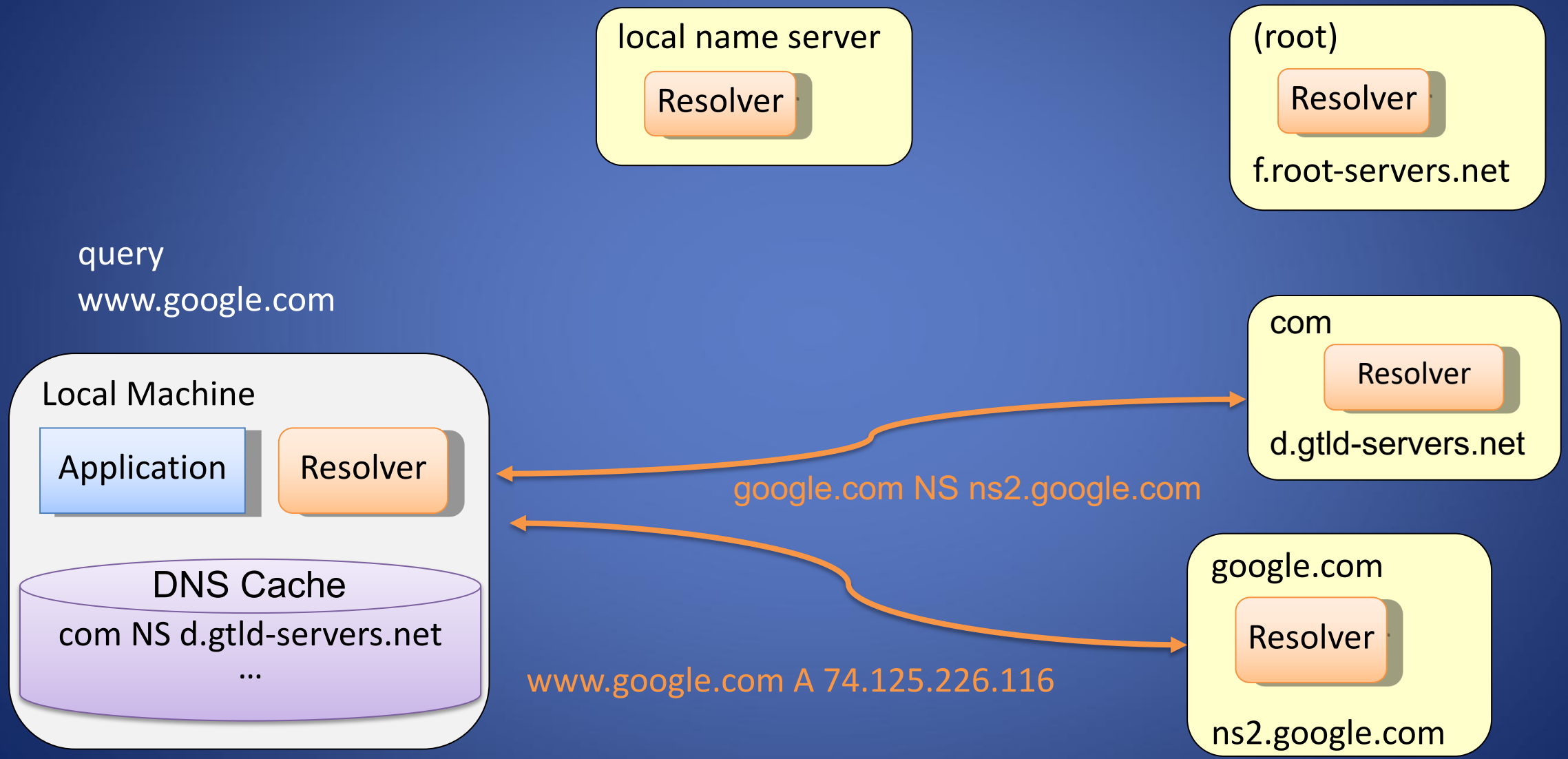
- Circular references
  - The authoritative name server for a domain may be within the same domain
  - E.g., dns.cs.brown.edu is authoritative for cs.brown.edu
- Glue record
  - Record of type A (IP address) for a name server referred to NS record
  - Essential to break circular references
- Example
  - brown.edu. NS bru-ns1.brown.edu.
  - bru-ns1.brown.edu. A 128.148.248.11 [glue record]

DNS Caching

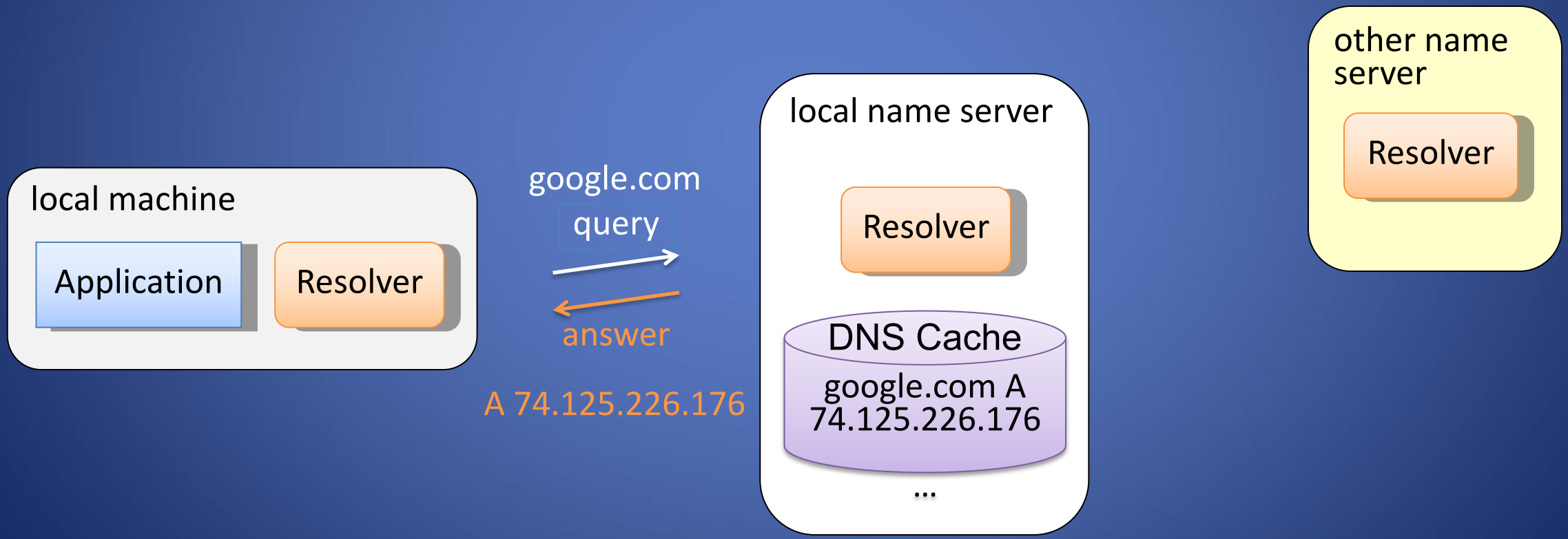
DNS Caching

- There would be too much network traffic if a path in the DNS tree would be traversed for each query
  - Root servers and TLD servers would be rapidly overloaded
- DNS servers cache records that are results of queries for a specified amount of time
  - Time-to-live field
- DNS queries with caching
  - First, resolver looks in cache for A record of query domain
  - Next , resolver looks in cache for NS record of longest suffix of query domain

Iterative Name Resolution with Caching



Recursive Name Resolution with Caching



Local DNS Cache

- Operating system and some applications (e.g., browsers) maintain local DNS cache
- Operating system DNS cache
  - On some versions, DNS cache is shared among all running processes
  - Can be displayed by all users
  - View DNS cache in Windows with command ipconfig /displaydns
  - Clear DNS cache in Windows with command ipconfig /flushdns
- Privacy issues with shared operating system DNS cache
  - Browsing by other users can be monitored
  - Note that private/incognito browsing does not clear DNS cache

Clicker Question (1)

Imagine the following name resolution protocol: the resolver looks in the cache of the local name server, finds a record of the query domain, and returns it to the client. What category does this fall under?

A. Iterative Name Resolution
B. Iterative Name Resolution with caching
C. Recursive Name Resolution
D. Recursive Name Resolution with caching
E. Both B and D

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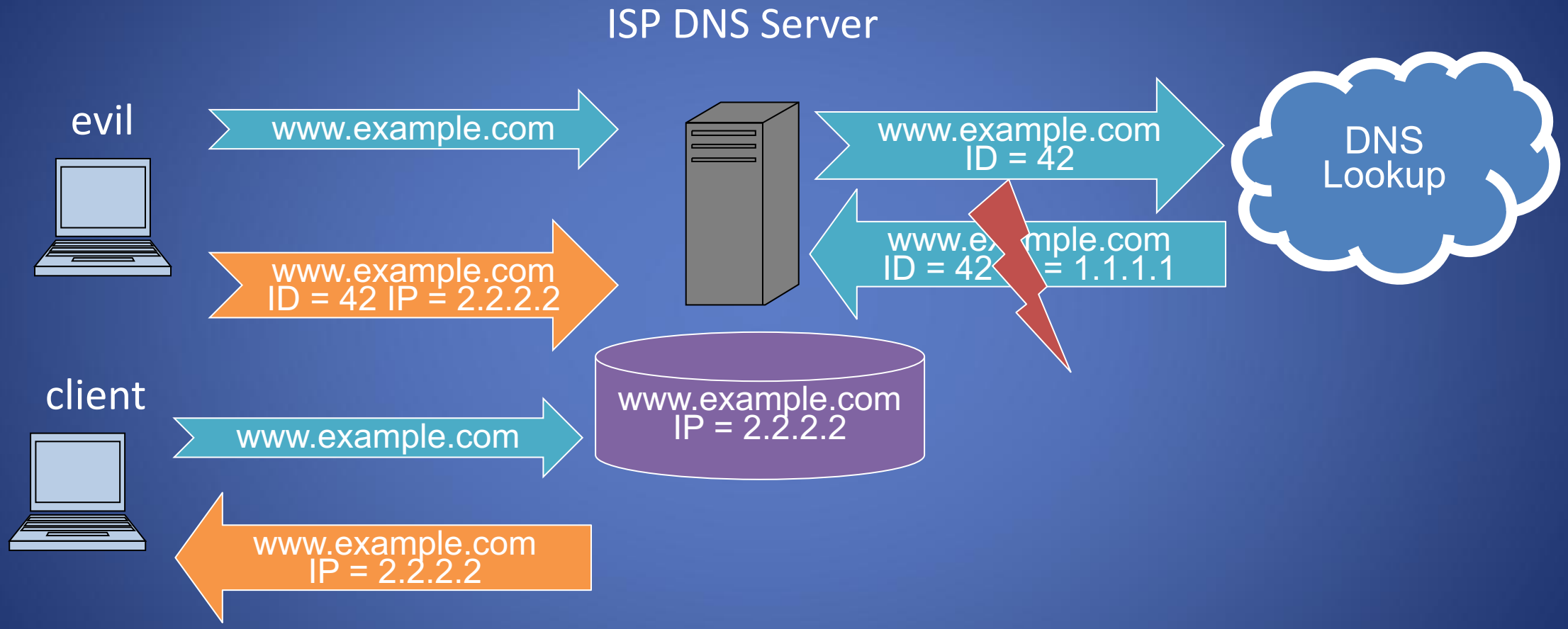
DNS Attacks

DNS Cache Poisoning

- Basic idea
  - Give a DNS server a false address record and get it cached
- DNS query mechanism
  - Queries issued over UDP on port 53
  - 16-bit request identifier in payload to match answers with queries
  - No authentication
  - No encryption
- Cache may be poisoned when a resolver
  - Disregards identifiers
  - Has predictable identifiers and return ports
  - Accepts unsolicited DNS records


ISP DNS Server
evil
www.example.com
www.example.com
ID = 42
DNS
Lookup
www.example.com
ID = 42 IP = 2.2.2.2
www.example.com
IP = 2.2.2.2
client
www.example.com
www.example.com
IP = 2.2.2.2

DNS Cache Poisoning Defenses

- Query randomization
  - Random request identifier (16 bits)
- Probability of guessing request ID or return port

$$1 / 2^{16} = 0.0015\%$$

- Check request identifier
- Use signed records
  - DNSSEC

Clicker Question

An attacker with a rogue machine on your local area network is sniffing traffic and wants to poison your DNS cache. Your DNS resolver uses both query ID and return port randomization. Is the poisoning attack going to succeed?

A. Not at all
B. Only with small probability $1 / 2^{16}$
C. Only with very small probability $1 / 2^{32}$
D. Likely

Clicker Question - Answer

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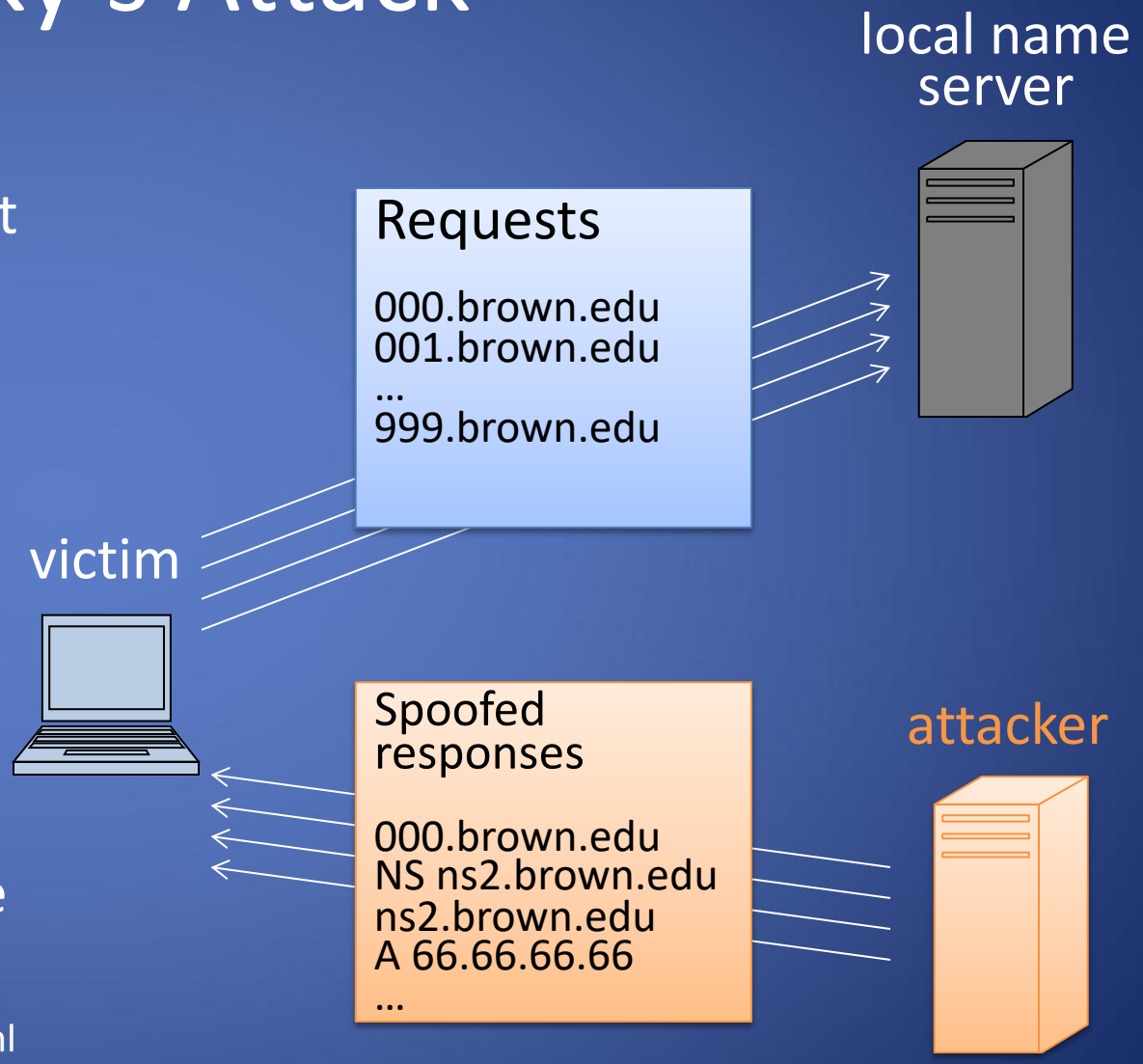
Kaminsky's Attack

- Attacker causes victim to send
  - Many DNS requests for nonexistent subdomains of target domain
- Attacker sends victim
  - Forged NS responses for the requests
- Format of forged response
  - Random ID
  - Correct NS record
  - Spoofed glue record pointing to the attacker's name server IP
- http://unixwiz.net/techtips/iguide-kaminsky-dns-vuln.html



DNS Cache Poisoning Defenses after Kaminsky's attack

- Query randomization
  - Random request identifier (16 bits)
  - **Random return port (16 bits)**
- Probability of guessing request ID or return port

  $1 / 2^{16} = 0.0015\%$
- **Probability of guessing request ID and return port is**

  $1 / 2^{32}$ (less than one in four billion)

- Check request identifier
- Use signed records
  - DNSSEC

DNS Hijacking/Redirecting

- Subvert the resolution of DNS queries
- **Malicious**: you type "bank.com" and attacker directs you to incorrect IP address
- **Censorship:** e.g. Great Firewall of China
- DoS: hacktivist can use to block dns resolution

- **ISPs:**
  - Display ads (instead of or in addition to existing ads),
  - Collect statistics about user traffic.
  - Block access to websites.

Denial-of-Service (DOS)

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Idea: Disrupt operation of a host or service by making it unable to fulfill requests

- Attack on availability

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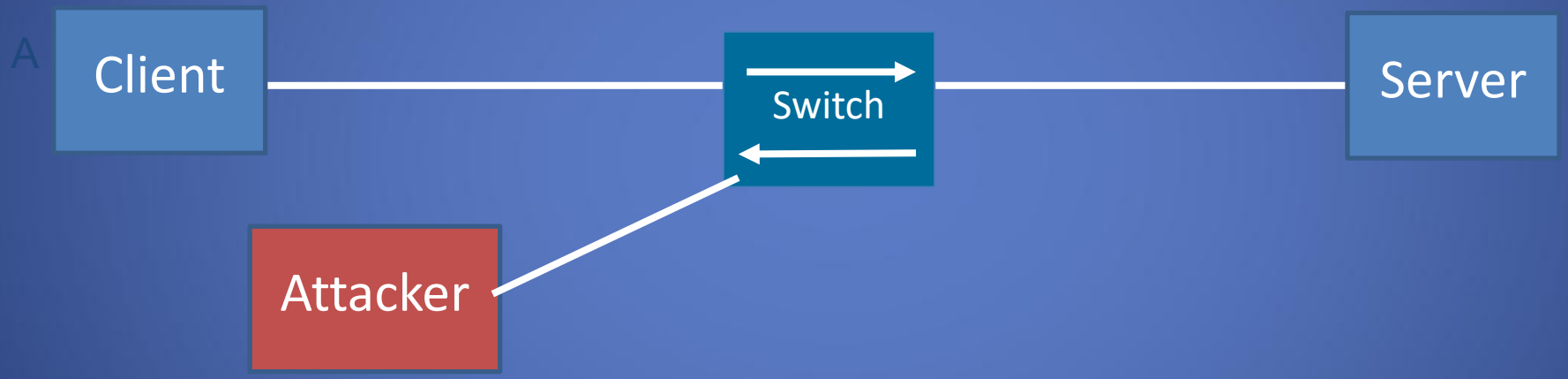
How?

- Overwhelm the target with with messages
- Disrupt some resource the target requires for operation (ie, power, network connectivity, OS, DNS, ...)

How it works

Network-based: exhaust target's available network bandwidth for handling legitimate traffic



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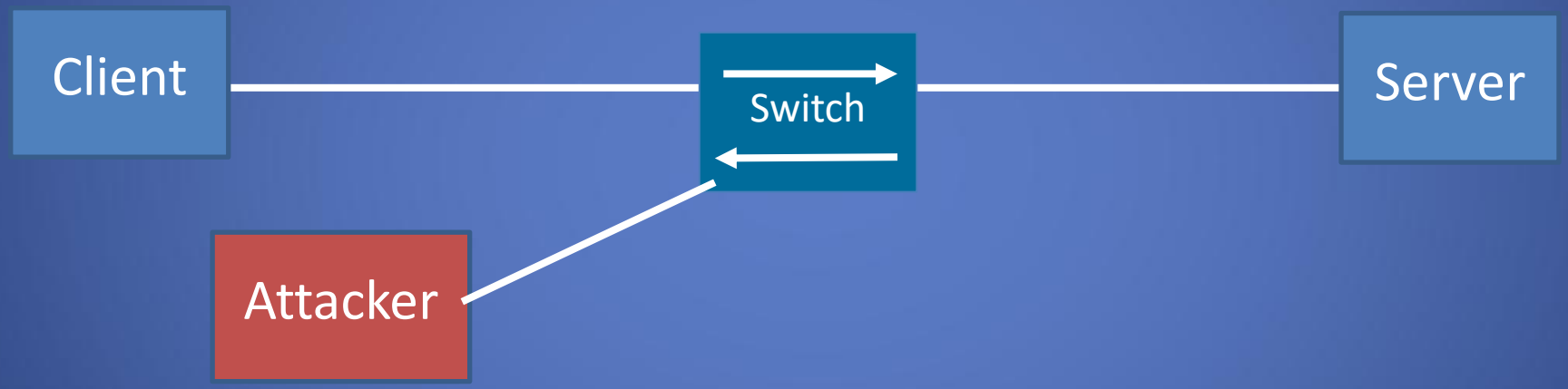
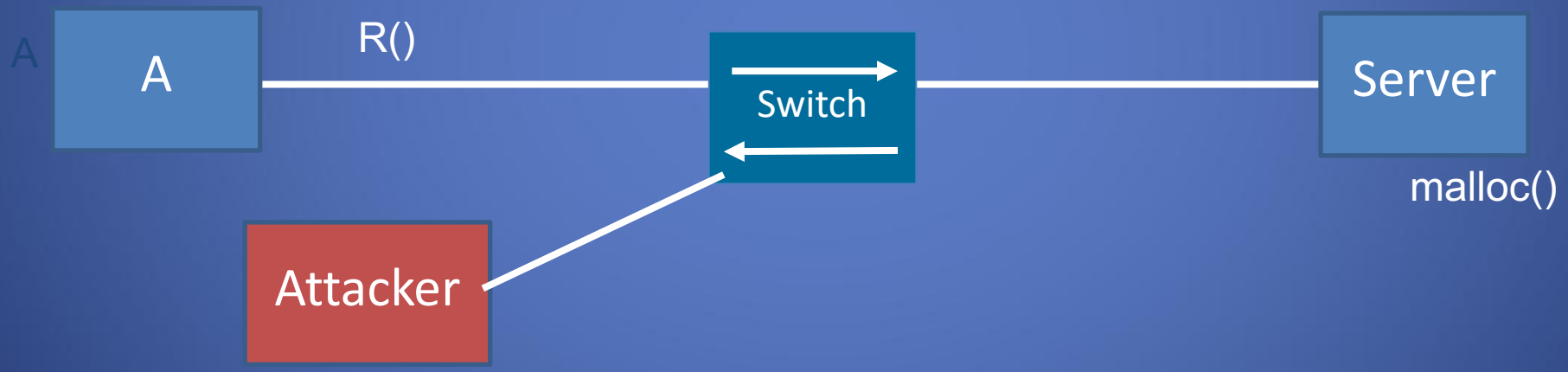


If attacker can generate traffic at a rate that exceeds B's bottleneck link capacity, legitimate packets will be dropped!

How it works

Application/OS-based: exhaust some resource used by target OS or application (eg. using all available memory)

Eg. What if request R forces server to call malloc()?



Attacker sends lots of requests of type R
=> server uses all memory, can't respond to actual requests

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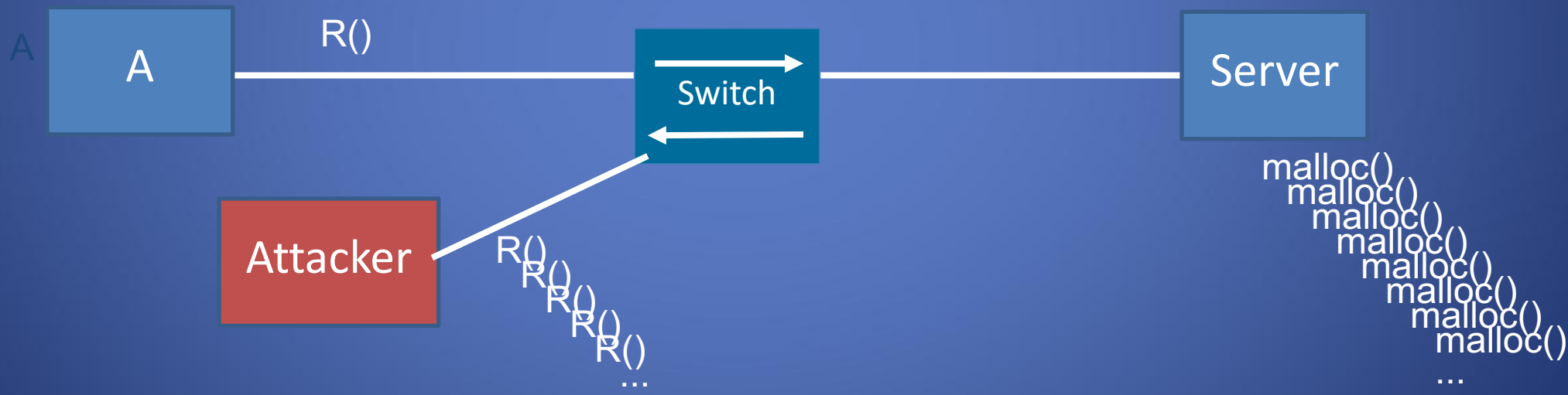

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Distributed Denial-of-Service (DDoS)

- Single attacker: limited by attacker's bandwidth, ability to make requests, ...
- Can have much higher impact if attack is distributed across many hosts

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- Can have much higher impact if attack is distributed across many hosts

How?

- Usually: attacker controls a botnet: a huge group of small, infected machines that send packets on its behalf
- Modern botnets are complex and highly-distributed systems—as complex as the cloud services they attack!

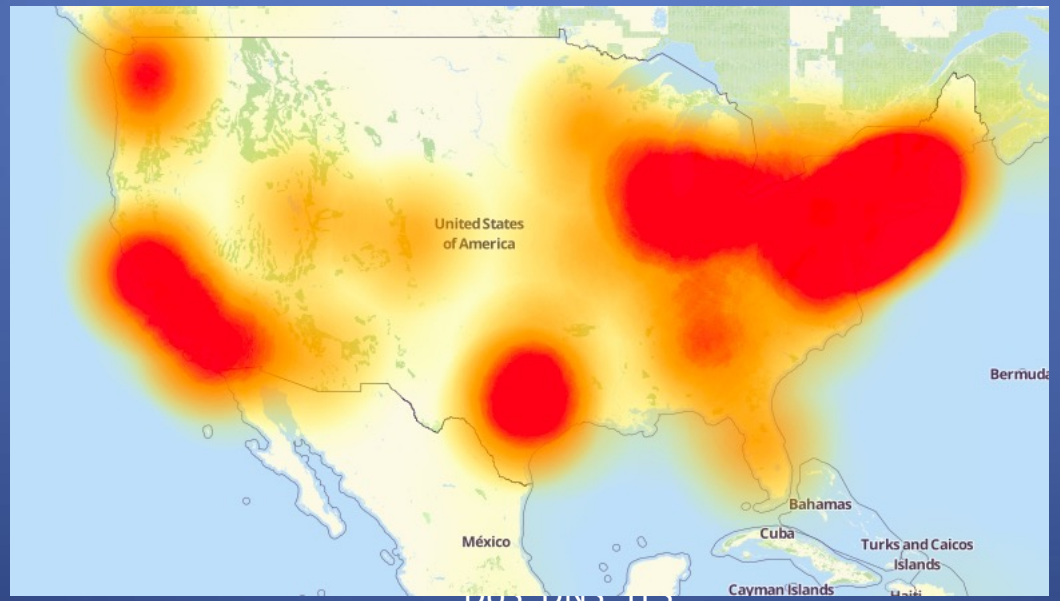
DDoS: Targets

- Small scale:

DNS as a Target

- Oct. 21 2016: Spotify, Reddit, NYT, Wired, and many more became partially unavailable from the East Coast.
- **Dyn** provides DNS services to these companies, and was targeted with a massive DDoS attack.

  => Caused by Mirai botnet: >500K infected consumer devices



Link

Example: Mirai Botnet

- Responsible for some of the largest DDoS attacks observed and studied
- Composed of cheap, insecure Internet of Things (IoT) devices
  - Consumer products: cameras, DVRs, home routers, …
  - Primary vulnerability: weak login credentials
- Infected ~65K devices in first hour, ~200-300K steady state

Actually a complex distributed system!
Really good writeup/talk here

Password	Device Type	Password	Device Type	Password	Device Type
123456	ACTi IP Camera	klv1234	HiSilicon IP Camera	1111	Xerox Printer
anko	ANKO Products DVR	jvbzd	HiSilicon IP Camera	Zte521	ZTE Router
pass	Axis IP Camera	admin	IPX-DDK Network Camera	1234	Unknown
888888	Dahua DVR	system	IQinVision Cameras	12345	Unknown
666666	Dahua DVR	meinsm	Mobotix Network Camera	admin1234	Unknown
vizxv	Dahua IP Camera	54321	Packet8 VOIP Phone	default	Unknown
7ujMko0vizxv	Dahua IP Camera	00000000	Panasonic Printer	fucker	Unknown
7ujMko0admin	Dahua IP Camera	realtek	RealTek Routers	guest	Unknown
666666	Dahua IP Camera	1111111	Samsung IP Camera	password	Unknown
dreambox	Dreambox TV Receiver	xmhdipc	Shenzhen Anran Camera	root	Unknown
juantech	Guangzhou Juan Optical	smcadmin	SMC Routers	service	Unknown
xc3511	H.264 Chinese DVR	ikwb	Toshiba Network Camera	support	Unknown
OxhlwSG8	HiSilicon IP Camera	ubnt	Ubiquiti AirOS Router	tech	Unknown
cat1029	HiSilicon IP Camera	supervisor	VideoIQ	user	Unknown
hi3518	HiSilicon IP Camera	<none>	Vivotek IP Camera	zlxx.	Unknown
klv123	HiSilicon IP Camera				

Table 5: **Default Passwords**—The 09/30/2016 Mirai source release included 46 unique passwords, some of which were traceable to a device vendor and device type. Mirai primarily targeted IP cameras, DVRs, and consumer routers.

Mirai: Capabilities

Mirai was a DDoS-for-hire service

- Received commands from control network with DDoS targets
- Various types of DDoS attacks supported
- Up to 600Gbps total bandwidth at its peak

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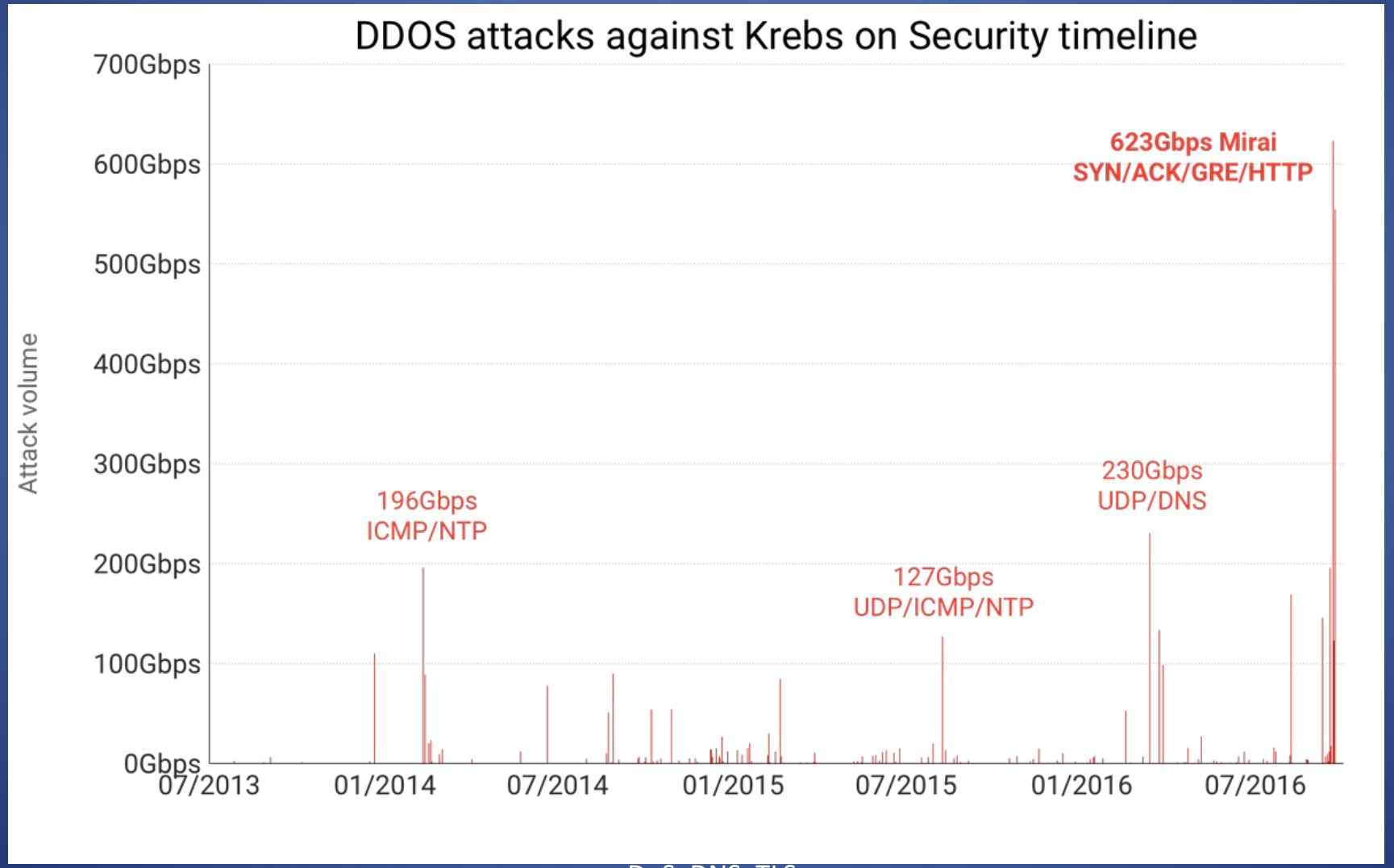
- Various types of DDoS attacks supported
- Up to 600Gbps total bandwidth at its peak

Original version shut down (and author arrested), but code was open-sourced

- Lots of evolution since then
- See link for details

Example


DDOS attacks against Krebs on Security timeline
Attack volume
700Gbps
600Gbps
500Gbps
400Gbps
300Gbps
200Gbps
100Gbps
0Gbps
07/2013
01/2014
07/2014
01/2015
07/2015
01/2016
07/2016
623Gbps Mirai
SYN/ACK/GRE/HTTP
230Gbps
UDP/DNS
196Gbps
ICMP/NTP
127Gbps
UDP/ICMP/NTP

How to perform a DDoS?

Idea: flood target with lots of packets

What types of packets? Need...

- Small packets (easy to send, low-bandwidth)
- Causes resource usage on target

A few tricks to maximize attacker's capabilities...

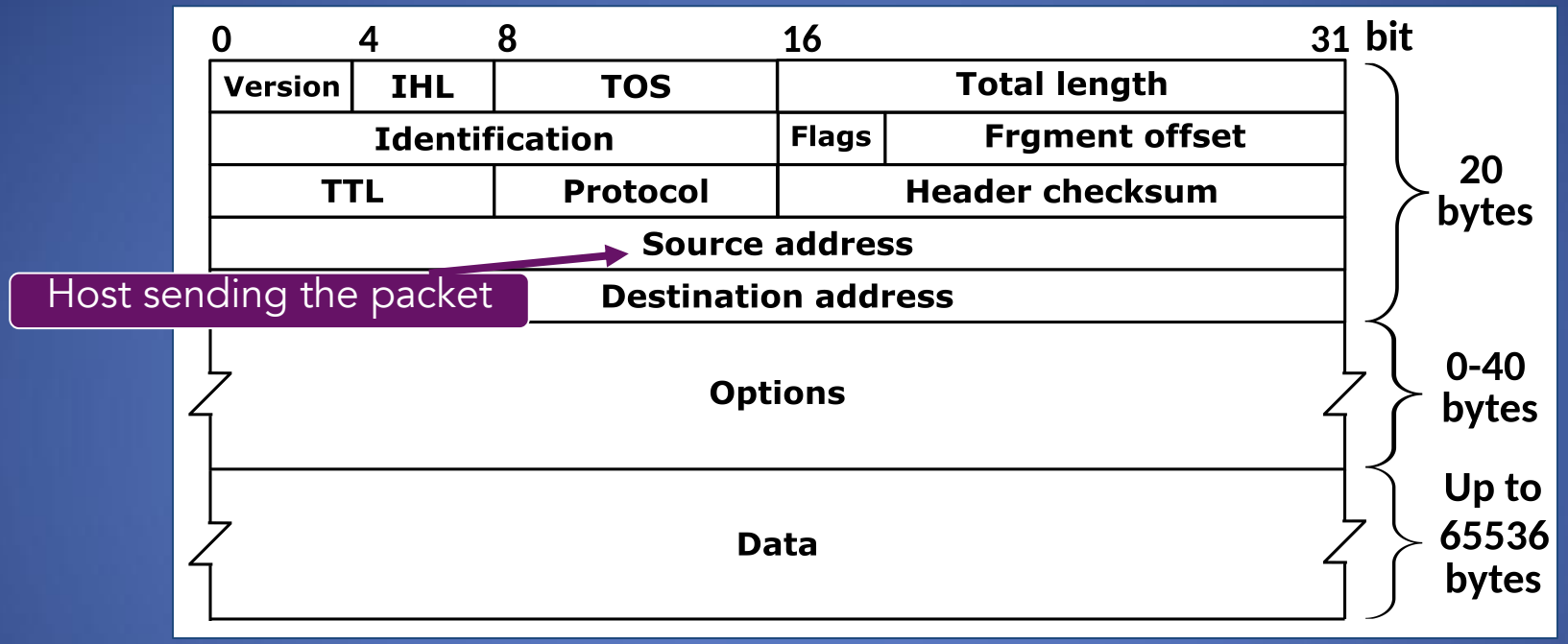
Examples of attack types

- HTTP flood: request generates resources on host
- SYN/ACK: TCP resource exhaustion (more on this later)
- NTP: application vulnerability would cause crashes
- DNS flood

Attack Type	Attacks	Targets	Class
HTTP flood	2,736	1,035	A
UDP-PLAIN flood	2,542	1,278	V
UDP flood	2,440	1,479	V
ACK flood	2,173	875	S
SYN flood	1,935	764	S
GRE-IP flood	994	587	A
ACK-STOMP flood	830	359	S
VSE flood	809	550	A
DNS flood	417	173	A
GRE-ETH flood	318	210	A

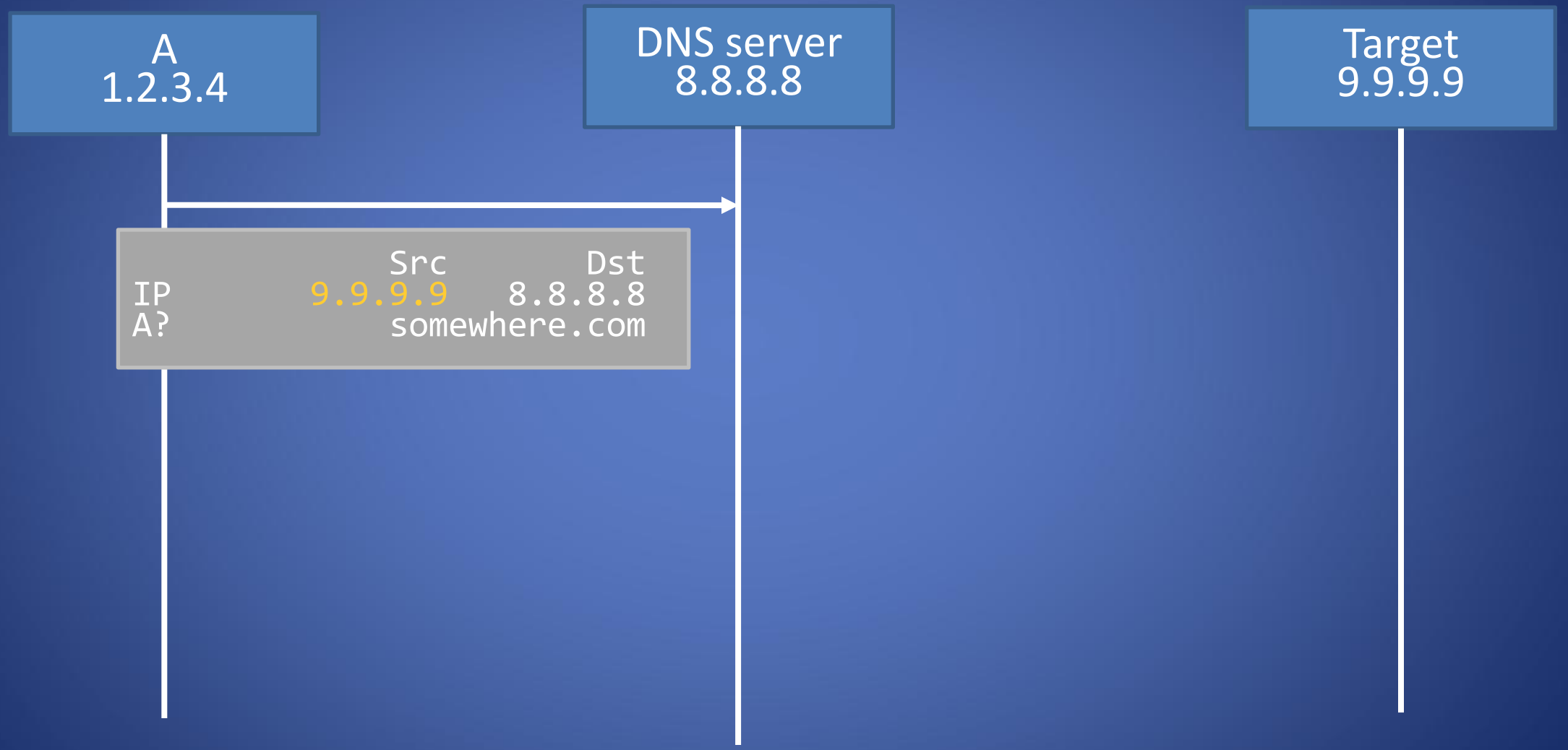
Table 9: **C2 Attack Commands**—Mirai launched 15,194 attacks between September 27, 2016–February 28, 2017. These include [A]pplication-layer attacks, [V]olumetric attacks, and TCP [S]tate exhaustion, all of which are equally prevalent.

Tricks: IP address spoofing

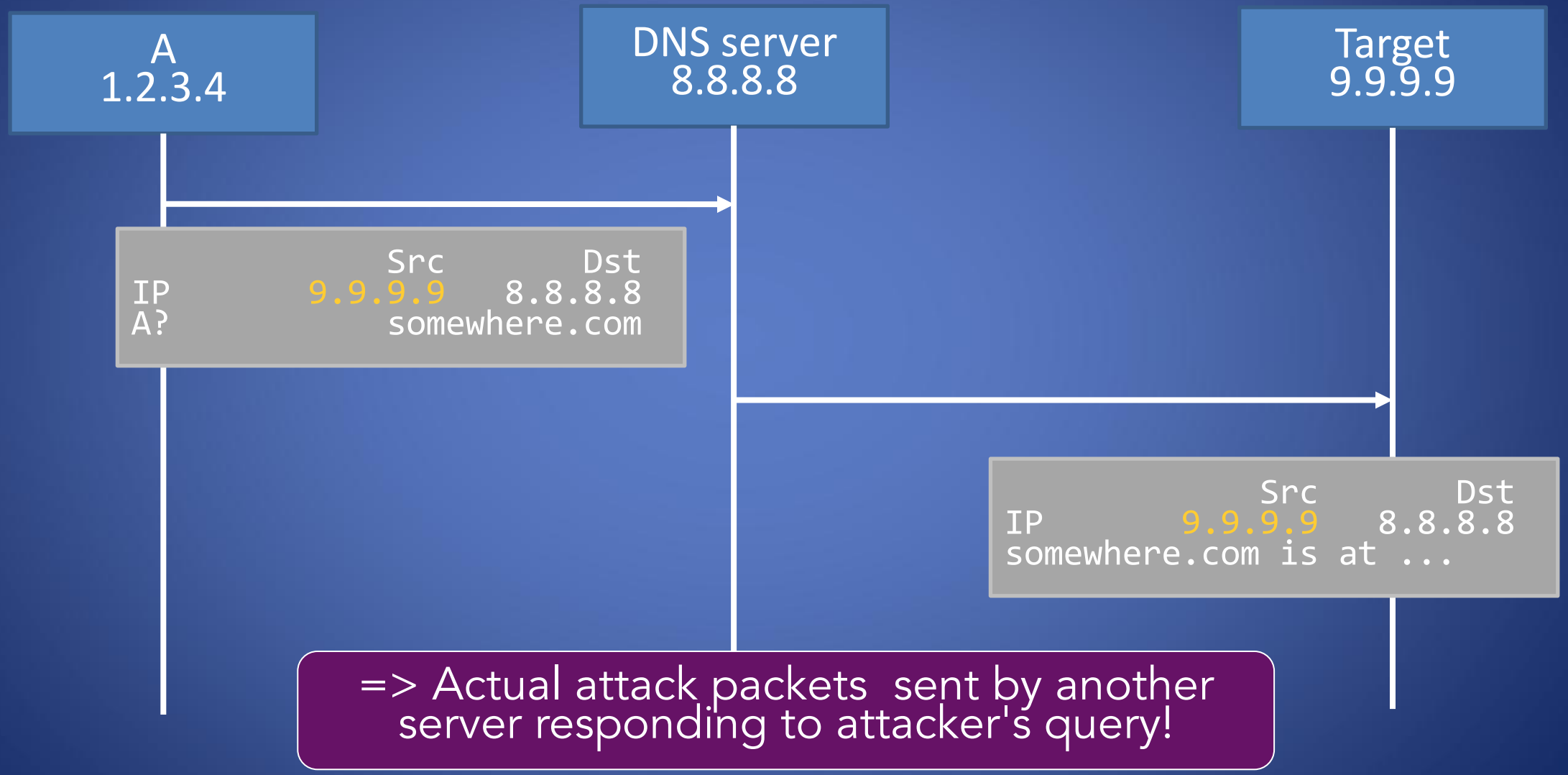


- Many networks don't actually check the IP source field
- Attacker can send packets with a spoofed address
  - Harder to detect source, can help with attack efficiency...

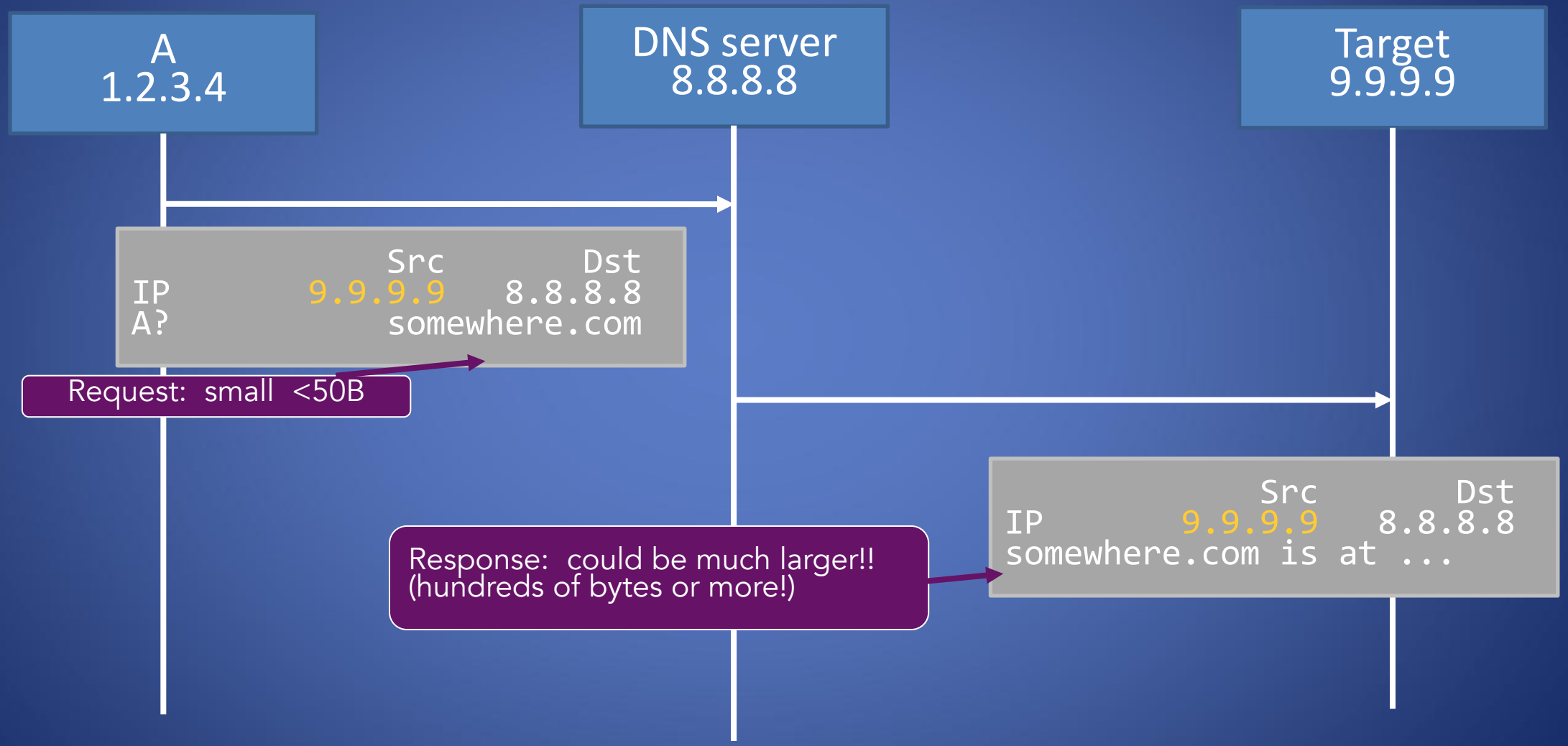
IP spoofing


A
1.2.3.4
DNS server
8.8.8.8
Target
9.9.9.9
Src
Dst
IP
9.9.9.9
8.8.8.8
A?
somewhere.com

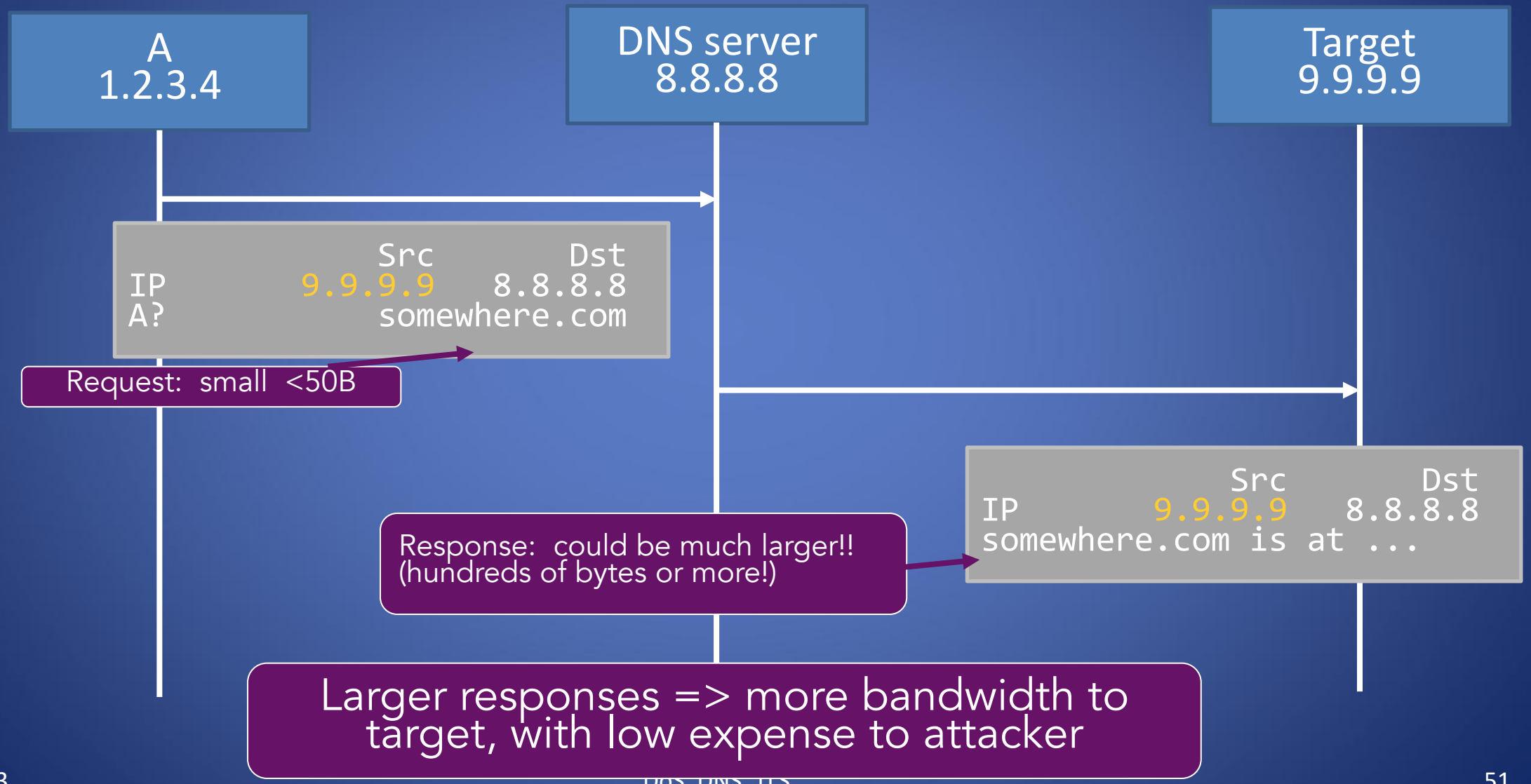
IP spoofing


A
1.2.3.4
DNS server
8.8.8.8
Target
9.9.9.9
Src Dst
IP 9.9.9.9 8.8.8.8
A? somewhere.com
Src Dst
IP 9.9.9.9 8.8.8.8
somewhere.com is at ...
=> Actual attack packets sent by another server responding to attacker's query!

IP spoofing with amplification



IP spoofing with amplification



Defenses: Single host

- Attempt #1: Make sure you have enough memory
  - How much is “enough”?
  - Depends on your threat model (how many resources do you think the attacker has?); might be hard to know
  - …and highly motivated adversary will just find (your limit + 1) resource
- Attempt #2: Firewall
  - Identify evil IP addresses; refuse service to them
  - Users might not use the same IP address

    Can’t authenticate a user (i.e. via password) because we need an established connection to do that!
  - Attacker can spoof addresses

Defenses?

- Attempt #3: Outsource it
  - Someone with lots of memory
  - Someone with lots of network bandwidth

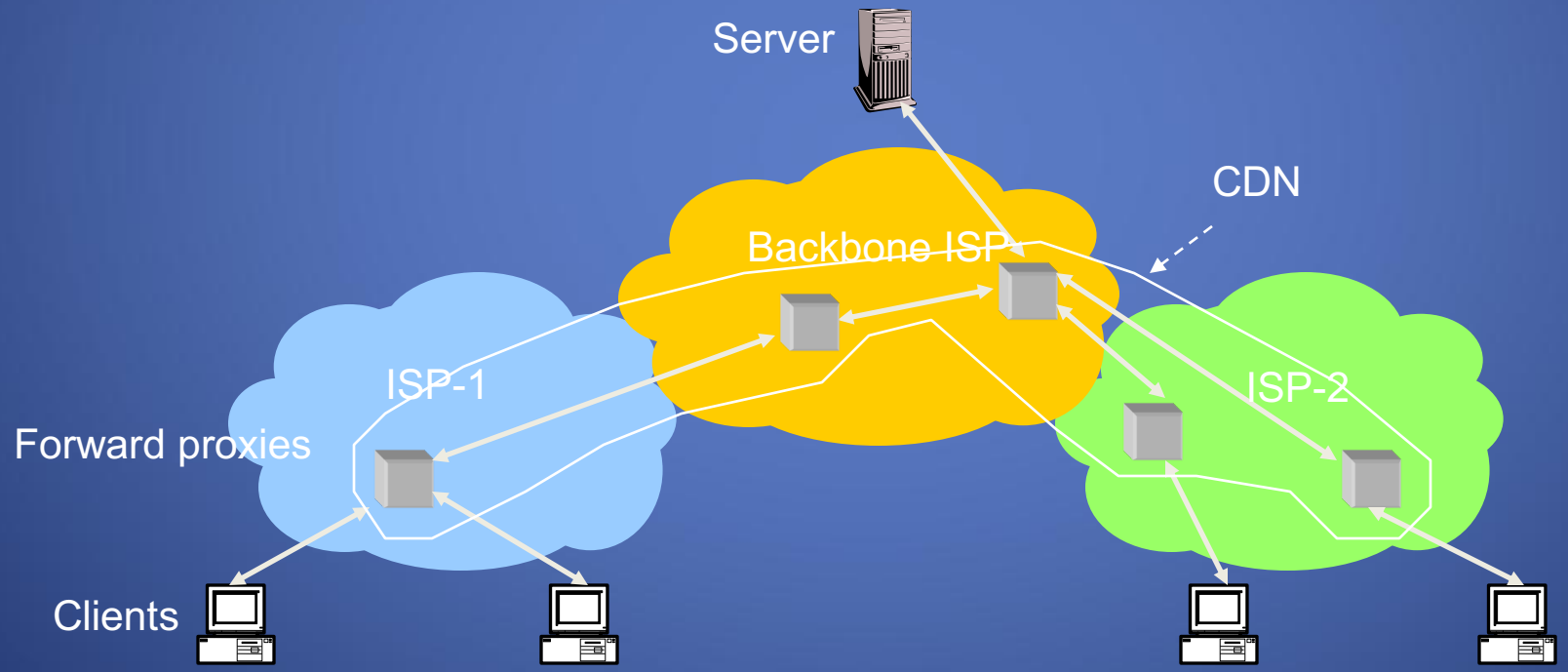
Who has this?

- Large cloud companies
- Content Distribution Networks (CDNs)

=> Often provide DDoS mitigation services

Content Distribution Networks (high level)

- Cloud services with widely-distributed networks
- Can act as caches or proxies for other applications or services



Example: Cloudflare

The Cloudflare global network

Our vast global network, which is one of the fastest on the planet, is trusted by millions of web properties.

With direct connections to nearly every service provider and cloud provider, the Cloudflare network can reach 95% of the world's population within approximately 50 ms.

285
cities in 100+ countries, including mainland China

11,500
networks directly connect to Cloudflare, including every major

192 Tbps
global network edge capacity, consisting of transit connections,

~50 ms
from 95% of the world's Internet-connected population

Demo: How Akamai works

- Akamai (another CDN) has cache servers deployed close to clients
  - Co-located with many ISPs
- Challenge: make same domain name resolve to a proxy close to the client
- Lots of DNS tricks. BestBuy is a customer
  - Delegate name resolution to Akamai (via a CNAME)

From Brown:

```
dig www.bestbuy.com
;; ANSWER SECTION:
www.bestbuy.com.    3600      IN   CNAME     www.bestbuy.com.edgesuite.net.
www.bestbuy.com.edgesuite.net. 21600 IN CNAME     a1105.b.akamai.net.
a1105.b.akamai.net. 20   IN   A    198.7.236.235
a1105.b.akamai.net. 20   IN   A    198.7.236.240
```

  - Ping time: 2.53ms

From Berkeley, CA:

```
a1105.b.akamai.net. 20   IN   A    198.189.255.200
a1105.b.akamai.net. 20   IN   A    198.189.255.207
```

  - Ping time: 3.20ms

DNS Resolution

```
dig www.bestbuy.com
;; ANSWER SECTION:
www.bestbuy.com.   3600      IN   CNAME    www.bestbuy.com.edgesuite.net.
www.bestbuy.com.edgesuite.net. 21600 IN   CNAME    a1105.b.akamai.net.
a1105.b.akamai.net.    20    IN   A    198.7.236.235
a1105.b.akamai.net.    20    IN   A    198.7.236.240
;; AUTHORITY SECTION:
b.akamai.net.      1101 IN   NS   n1b.akamai.net.
b.akamai.net.      1101 IN   NS   n0b.akamai.net.
;; ADDITIONAL SECTION:
n0b.akamai.net.         1267 IN   A    24.143.194.45
n1b.akamai.net.         2196 IN   A    198.7.236.236
```

- n1b.akamai.net finds an edge server close to the client's local resolver
  - Uses knowledge of network: BGP feeds, traceroutes. *Their secret sauce…*

Example

```
dig www.bestbuy.com
;; QUESTION SECTION:
;www.bestbuy.com. IN A

;; ANSWER SECTION:
www.bestbuy.com. 2530 IN CNAME www.bestbuy.com.edgekey.net.
www.bestbuy.com.edgekey.net. 85 IN CNAME e1382.x.akamaiedge.net.
e1382.x.akamaiedge.net. 16 IN A 104.88.86.223

;; Query time: 6 msec
;; SERVER: 192.168.1.1#53(192.168.1.1)
;; WHEN: Thu Nov 16 09:43:11 2017
;; MSG SIZE  rcvd: 123

traceroute to 104.88.86.223 (104.88.86.223), 64 hops max, 52 byte packets
 1  router (192.168.1.1)  2.461 ms  1.647 ms  1.178 ms
 2  138.16.160.253 (138.16.160.253)  1.854 ms  1.509 ms  1.462 ms
 3  10.1.18.5 (10.1.18.5)  1.886 ms  1.705 ms  1.707 ms
 4  10.1.80.5 (10.1.80.5)  4.276 ms  6.444 ms  2.307 ms
 5  lsb-inet-r-230.net.brown.edu (128.148.230.6)  1.804 ms  1.870 ms  1.727 ms
 6  131.109.200.1 (131.109.200.1)  2.841 ms  2.587 ms  2.530 ms
 7  host-198-7-224-105.oshean.org (198.7.224.105)  4.421 ms  4.523 ms  4.496 ms
 8  5-1-4.bear1.boston1.level3.net (4.53.54.21)  4.099 ms  3.974 ms  4.290 ms
 9  * ae-4.r00.bstnma07.us.bb.gin.ntt.net (129.250.66.93)  4.689 ms  4.109 ms
10  ae-6.r24.nycmny01.us.bb.gin.ntt.net (129.250.4.114)  8.863 ms  10.205
ms  10.477 ms
11  ae-1.r08.nycmny01.us.bb.gin.ntt.net (129.250.5.62)  9.298 ms
    ae-1.r07.nycmny01.us.bb.gin.ntt.net (129.250.3.181)  10.008 ms  8.677 ms
12  ae-0.a00.nycmny01.us.bb.gin.ntt.net (129.250.3.94)  8.543 ms  7.935 ms
    ae-1.a00.nycmny01.us.bb.gin.ntt.net (129.250.6.55)  9.836 ms
13  a104-88-86-223.deploy.static.akamaitechnologies.com (104.88.86.223)  9.470
ms  8.483 ms  8.738 ms
```

```
dig www.bestbuy.com @109.69.8.51

e1382.x.akamaiedge.net. 12 IN A 23.60.221.144


traceroute to 23.60.221.144 (23.60.221.144), 64 hops max, 52 byte packets
 1  router (192.168.1.1)  44.072 ms  1.572 ms  1.154 ms
 2  138.16.160.253 (138.16.160.253)  2.460 ms  1.736 ms  2.722 ms
 3  10.1.18.5 (10.1.18.5)  1.841 ms  1.649 ms  3.348 ms
 4  10.1.80.5 (10.1.80.5)  2.304 ms  15.208 ms  2.895 ms
 5  lsb-inet-r-230.net.brown.edu (128.148.230.6)  1.784 ms  4.744 ms  1.566 ms
 6  131.109.200.1 (131.109.200.1)  3.581 ms  5.866 ms  3.238 ms
 7  host-198-7-224-105.oshean.org (198.7.224.105)  4.288 ms  6.218 ms  8.332 ms
 8  5-1-4.bear1.boston1.level3.net (4.53.54.21)  4.209 ms  6.103 ms  5.031 ms
 9  ae-4.r00.bstnma07.us.bb.gin.ntt.net (129.250.66.93)  3.982 ms  5.824
ms  4.514 ms
10  ae-6.r24.nycmny01.us.bb.gin.ntt.net (129.250.4.114)  9.735 ms  12.442
ms  8.689 ms
11  ae-9.r24.londen12.uk.bb.gin.ntt.net (129.250.2.19)  81.098 ms  81.343
ms  81.120 ms
12  ae-6.r01.mdrdsp03.es.bb.gin.ntt.net (129.250.4.138)  102.009 ms  110.595
ms  103.010 ms
13  81.19.109.166 (81.19.109.166)  99.426 ms  93.236 ms  101.168 ms
14  a23-60-221-144.deploy.static.akamaitechnologies.com (23.60.221.144)  94.884
ms  92.779 ms  93.281 ms
```

Other DNS servers to try:
77.88.8.8 (St Petersburg),
89.233.43.71 (Copenhagen),
202.46.32.22(Beijing)

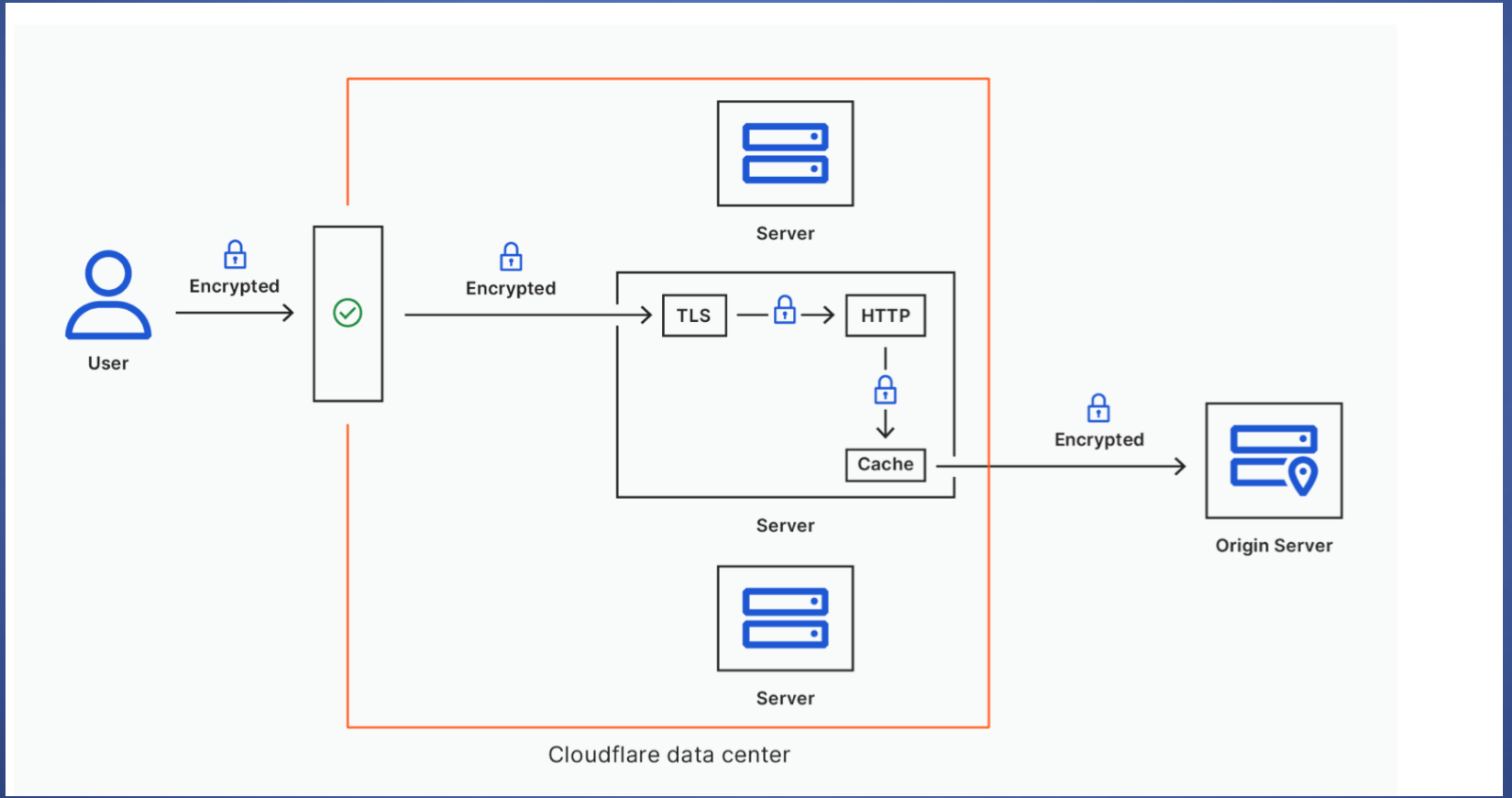
How CDNs prevent DDoS

- DDoS => Widely distributed attack, large bandwidth

vs.

- CDN => Widely distributed network, significant bandwidth
  - Distribute attack load across global scale
  - Also outsourced monitoring, analysis, etc.

Example: Cloudflare architecture



Demo: Anycast

- CDNs don't just work with DNS!

Transport Layer (Ports, TCP, UDP)

The Transport Layer

Network layer: moving data between hosts

Transport layer: Abstraction for getting data data to different *applications* on a host

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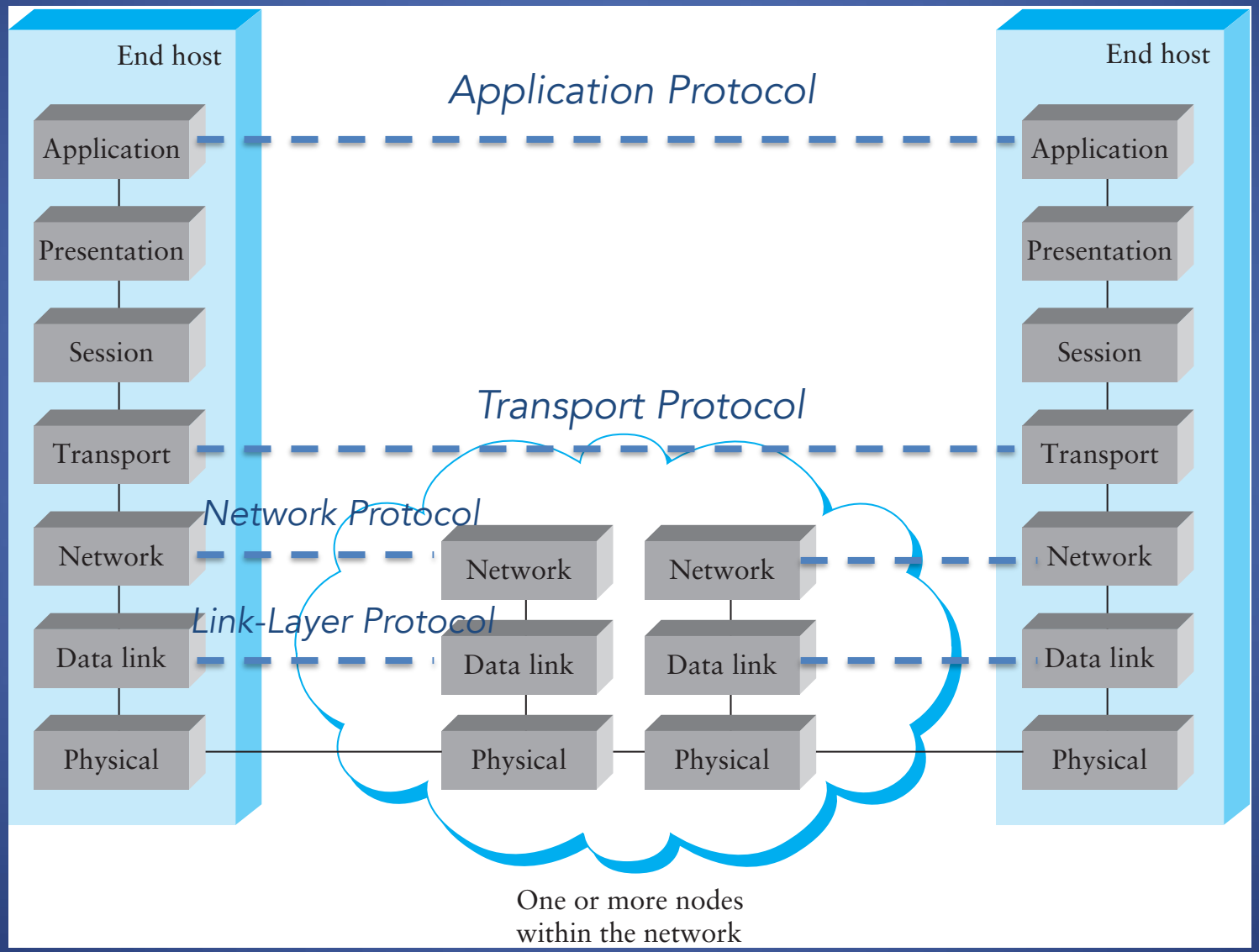
Network layer: moving data between hosts

Transport layer: Abstraction for getting data data to different *applications* on a host

- Multiplexing multiple connections at same IP with port numbers
- Series of packets => stream of data/messages
- May provide: reliable data delivery

Two key protocols: TCP, UDP

From earlier: OSI Model



What's a port number?

- 16-bit unsigned number, 0-65535
- Ports define a communication *endpoint*, usually a process/service on a host
- OS keeps track of which ports map to which applications

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- OS keeps track of which ports map to which applications

Port numbering

- port < 1024: "Well known port numbers"
- port >= 20000: "ephemeral ports", for general app. use

Some common ports

Port	Service
20, 21	File Transfer Protocol (FTP)
22	Secure Shell (SSH)
23	Telnet (pre-SSH remote login)
25	SMTP (Email)
53	Domain Name System (DNS)
67, 68	DHCP
80	HTTP (Web traffic)
443	HTTPS (Secure HTTP over TLS)

How ports work

Two modes:

- Applications "listen on" or "bind to" a port to wait for new connections

- Hosts make connections to a particular IP and port

How ports work

Two modes:

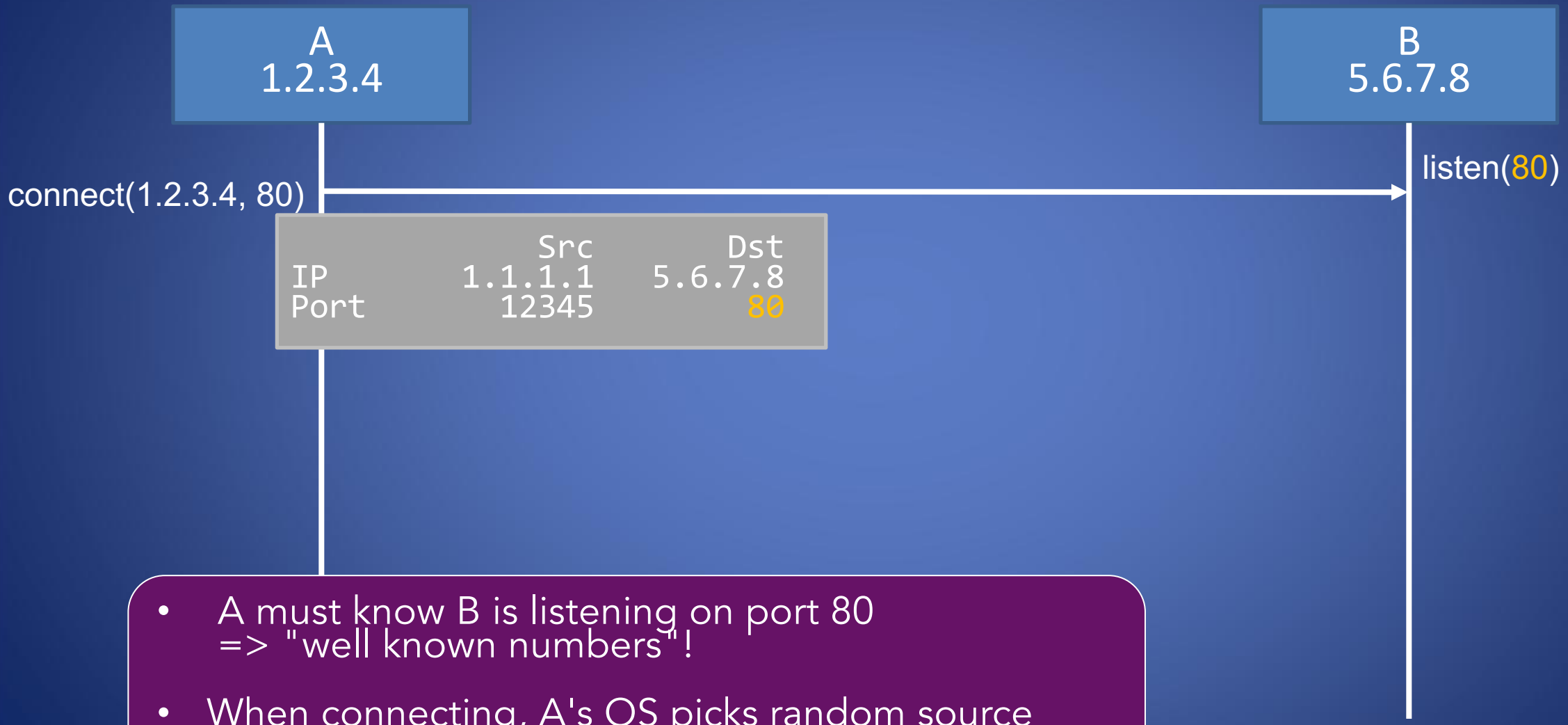
- Applications "listen on" or "bind to" a port to wait for new connections

  => Example: webserver listens on port 80

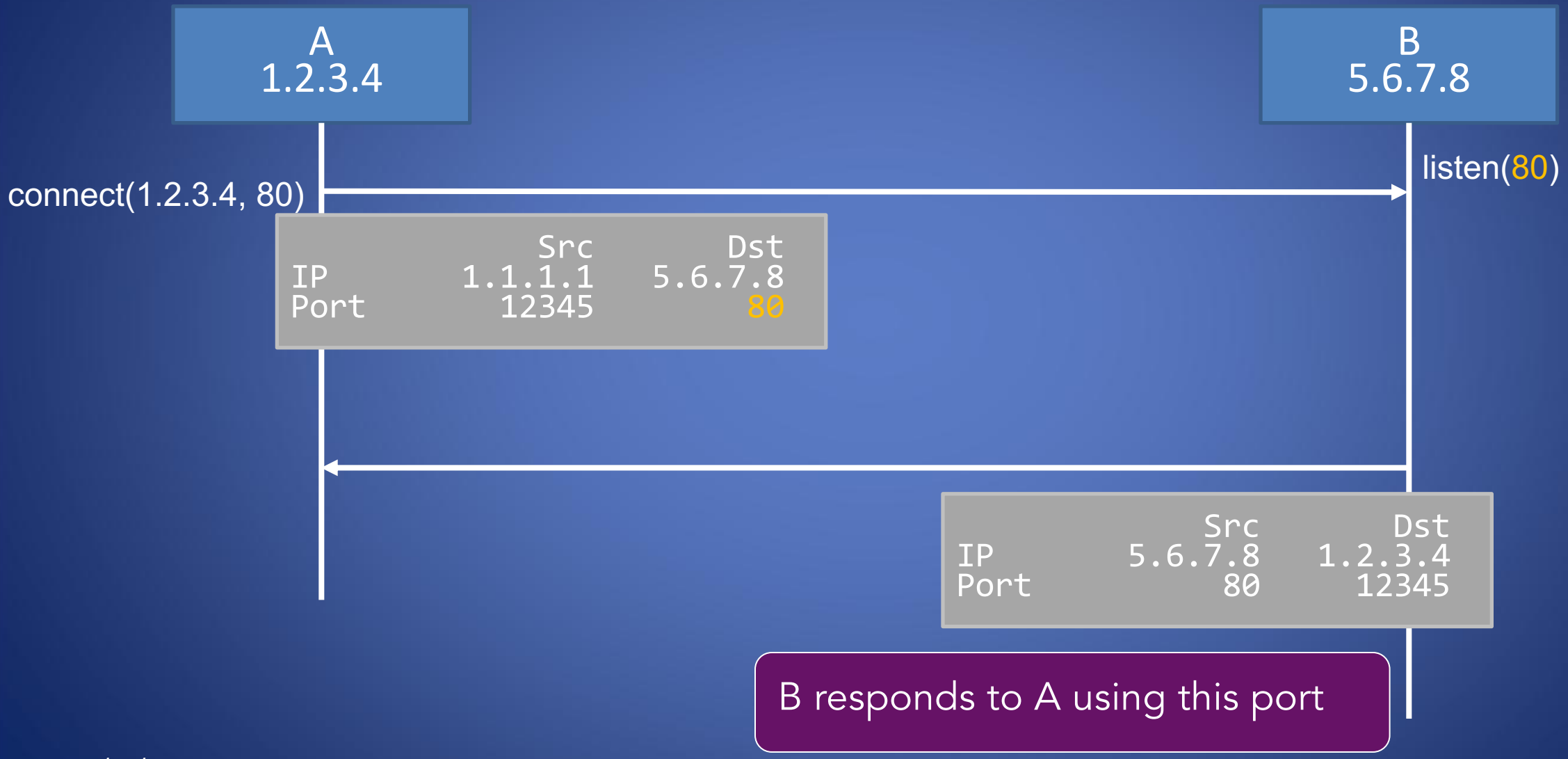
- Hosts make connections to a particular IP and port

  => Example: client connects to <webserver IP>, port 80

  (eg. 1.2.3.4:80)



- A must know B is listening on port 80
  => "well known numbers"!
- When connecting, A's OS picks random source port (eg. 12345), used for its side of connection


A
1.2.3.4
B
5.6.7.8
listen(80)
connect(1.2.3.4, 80)
Src
Dst
IP
1.1.1.1
5.6.7.8
Port
12345
80
Src
Dst
IP
5.6.7.8
1.2.3.4
Port
80
12345
B responds to A using this port

Sockets

OS keeps track of which application uses which port

Two types:

- Listening ports
- Connections between two hosts (src/dst port)

Socket: OS abstraction for a network connection, like a file descriptor

Table maps: port => socket

Want to know more? Take CS1680!

Netstat

```
deemer@vesta ~/Development % netstat -an
Active Internet connections (including servers)
Proto Recv-Q Send-Q  Local Address          Foreign Address        (state)
tcp4       0      0  10.3.146.161.51094     104.16.248.249.443     ESTABLISHED
tcp4       0      0  10.3.146.161.51076     172.66.43.67.443       ESTABLISHED
tcp6       0      0  2620:6e:6000:900.51074 2606:4700:3108::.443   ESTABLISHED
tcp4       0      0  10.3.146.161.51065     35.82.230.35.443       ESTABLISHED
tcp4       0      0  10.3.146.161.51055     162.159.136.234.443    ESTABLISHED
tcp4       0      0  10.3.146.161.51038     17.57.147.5.5223       ESTABLISHED
tcp6       0      0  *.22                   *.*                    LISTEN
tcp4       0      0  *.51036                *.*                    LISTEN
tcp4       0      0  127.0.0.1.9999         *.*                    LISTEN
```

`netstat -an`: Show all connections
`netstat -lnp`: Show listening ports + applications using them (as root)

Why do we care?

Ports define what services are exposed to the network

- Open port: can send data to application (reconnaissance, attacks, ...)

- Surface for DDoS
- OS and network hardware can monitor port numbers
  - Make decisions on how to filter/monitor traffic

Demo: netcat

Port scanning

What can we learn if we just start connecting to well-known ports?

- Can discover things about the network
- Can learn about vulnerabilities

How to defend ports?

Single system or organization

- Stateless: block specific ports, IP ranges
- Stateful: track connection state, block certain types of connection state

Large scale

- Distribute load/filtering in the network => cloud provider

Firewall policy example

What We Have Learned

- DoS in Networks
  - Attacks and defenses
- IP address Spoofing

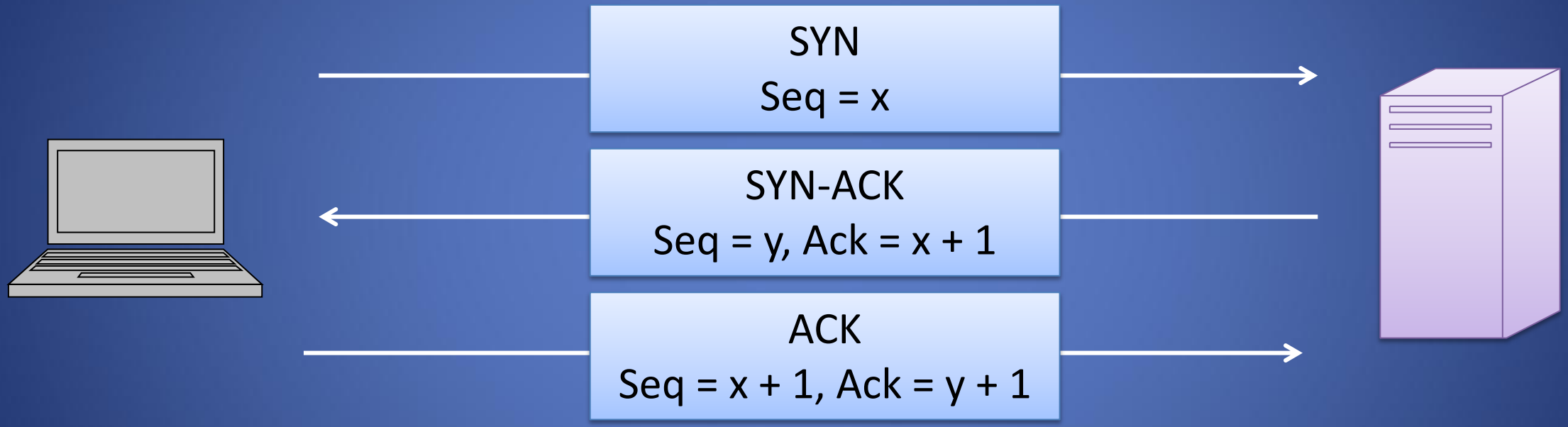
- How DNS operates
  - Distributed database
  - Resolvers and name servers
  - Iterative vs. recursive resolution
  - Caching
- DNS cache poisoning
- DNS Hijacking

References

- IETF RFC 5246 - The Transport Layer Security (TLS) Protocol Version 1.2 (2008)
- IETF RFC 8446 - The Transport Layer Security (TLS) Protocol Version 1.3 (2018)
- Logjam attack (2015)

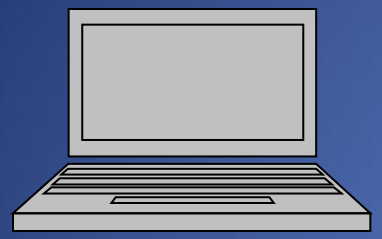
More on transport layer

Recall: TCP Establishment Handshake



What happens on the server?

Recall: TCP Establishment Handshake

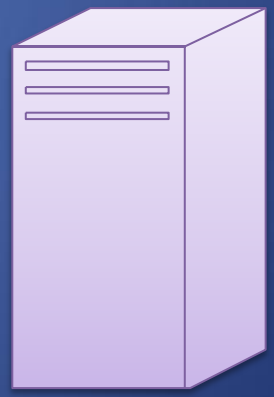


SYN
Seq = x

SYN-ACK
Seq = y, Ack = x + 1

ACK
Seq = x + 1, Ack = y + 1

Server creates **state** associated with connection (client IP, port, counters…)



What happens if client doesn't send this ACK?

Recall: TCP Establishment Handshake

SYN
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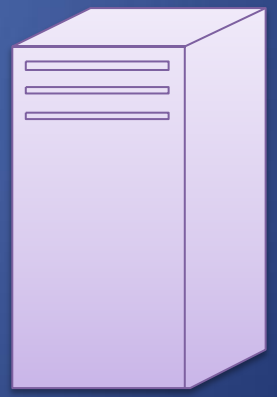


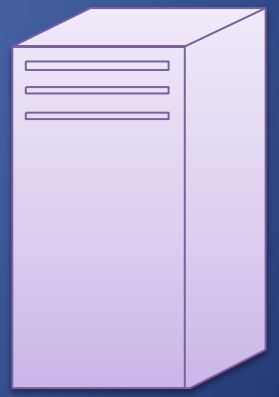
What happens if adversary doesn't send this ACK?

Recall: TCP Establishment Handshake

SYN
Seq = x

Server creates **state** associated with connection (client IP, port, counters…)

SYN-ACK
Seq = y, Ack = x + 1

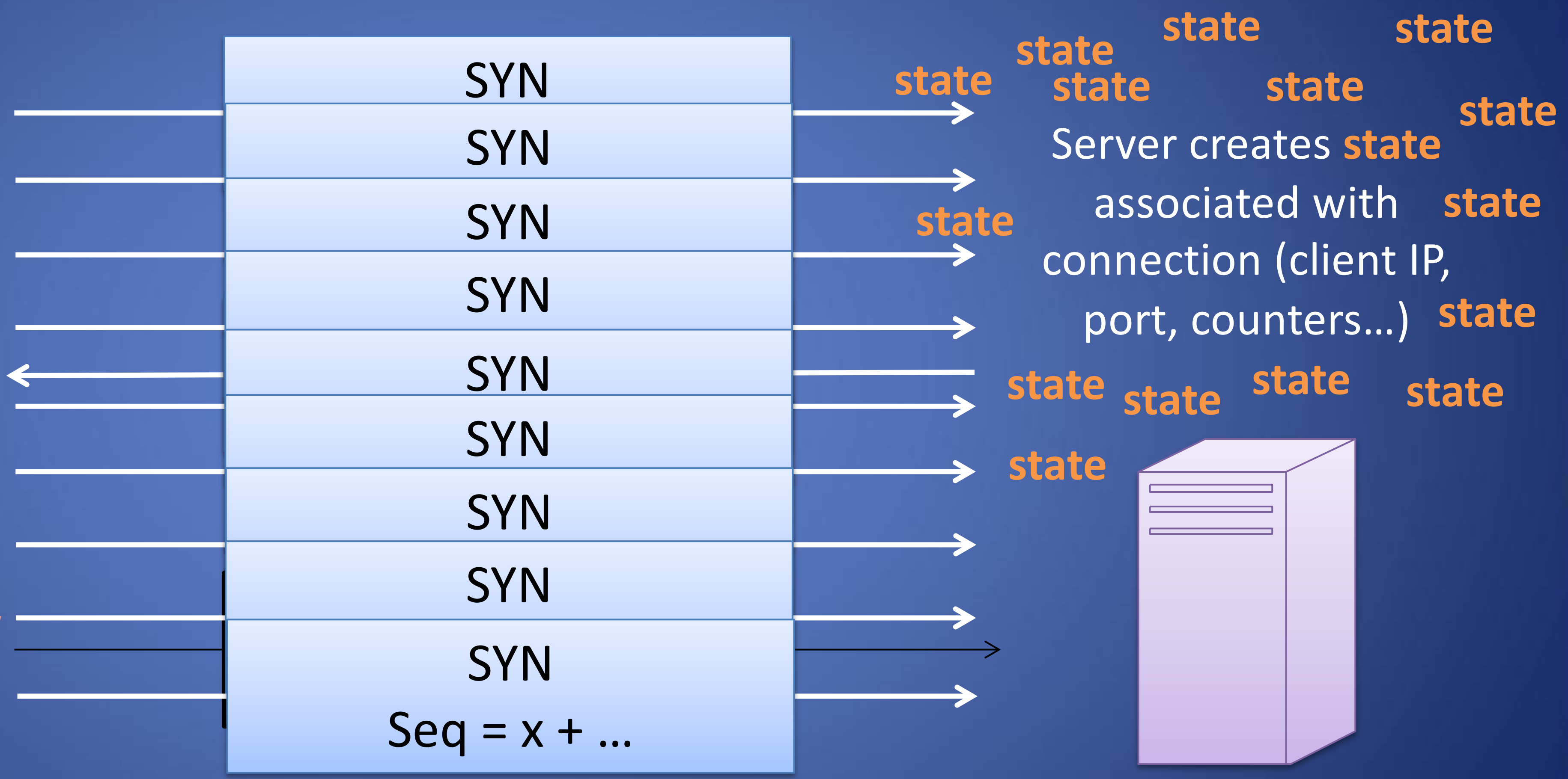


What happens if adversary doesn't send this ACK?

ACK
Seq = x + 1, Ack = y + 1

A single SYN from adversary forces the server to spend some memory…

Recall: TCP Establishment Handshake



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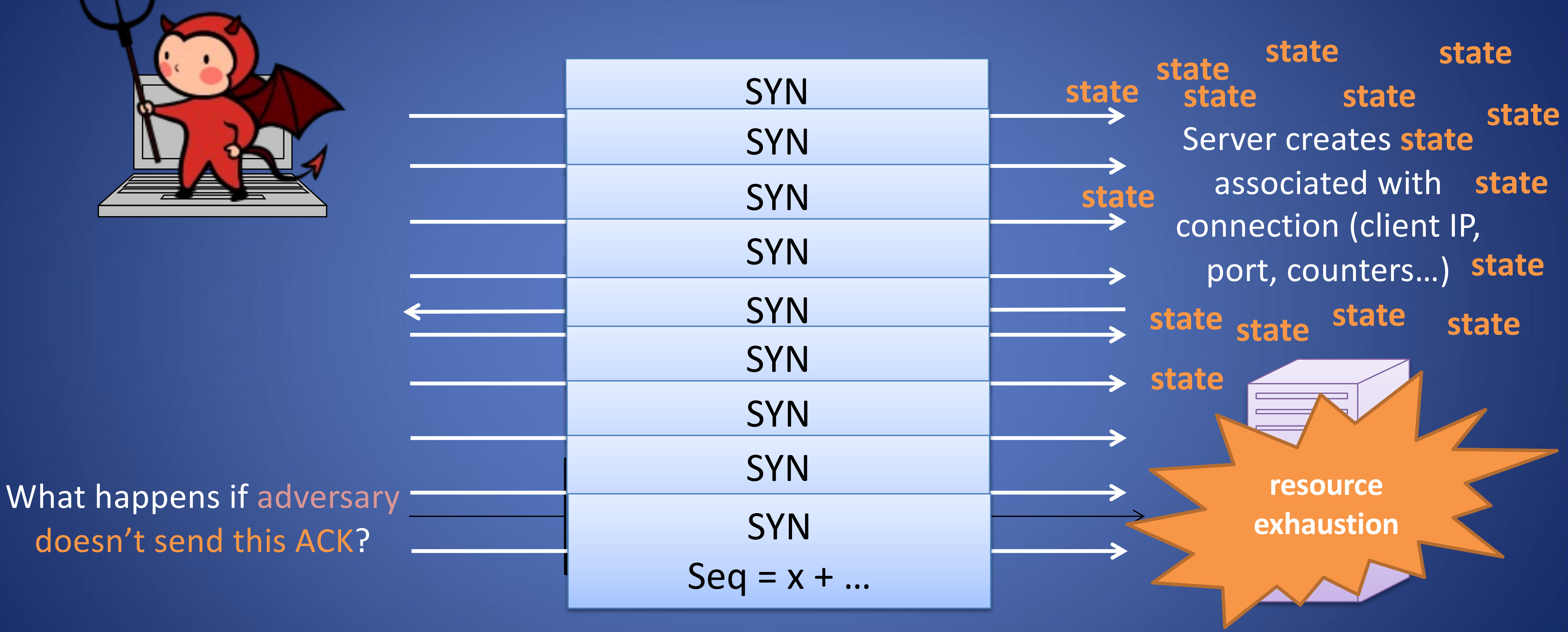
Recall: TCP Establishment Handshake



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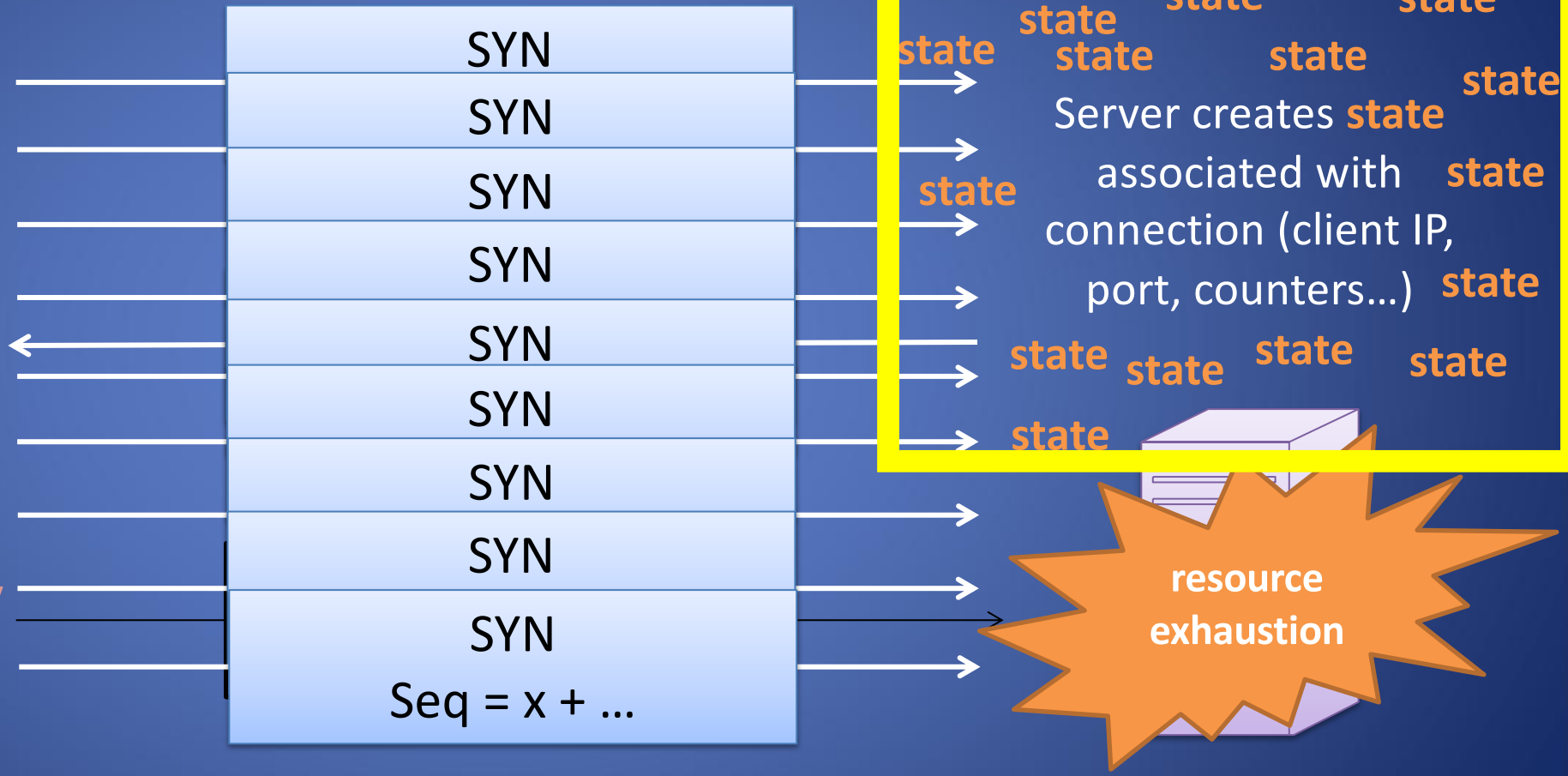


What happens if adversary doesn't send this ACK?

A single SYN from adversary forces the server to spend some memory…

SYN Flooding

- Attacker targets server memory rather than network capacity
- Every (unique) SYN forces the server to spend memory
  - Server can't necessarily clear up the memory (at least, not right away)
- What happens when the server runs out of memory?
  - Refuse new connection?

    Legitimate new users can't access service
  - Evict old connections?

    Legitimate old users get kicked out

Defenses?

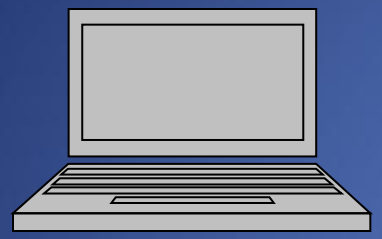
- Attempt #1: Make sure you have enough memory
  - How much is “enough”?
  - Depends on your threat model (how many resources do you think the attacker has?); might be hard to know
  - …and highly motivated adversary will just find (your limit + 1) resource
- Attempt #2: Firewall
  - Identify evil IP addresses; refuse service to them
  - Users might not use the same IP address

    Can’t authenticate a user (i.e. via password) because we need an established connection to do that!
  - Attacker can spoof addresses

Defenses?

- Attempt #3: Outsource it
  - Someone with lots of memory
  - Someone with lots of network bandwidth

Idea: Outsource Your State



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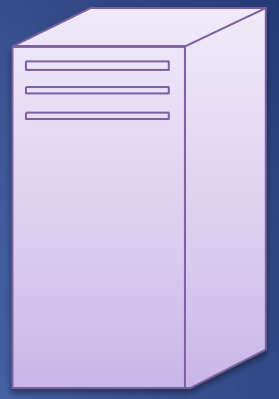


SYN-ACK
Seq = y, Ack = x + 1

<State>

Don't create **state** here; instead, give it to the client

Client sends back the state

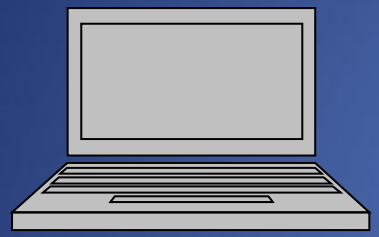
ACK
Seq = x + 1, Ack = y + 1

<State>

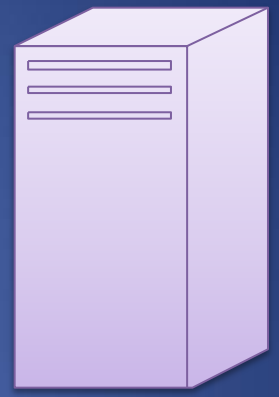
Server only saves **state** here

SYN Cookies

Idea: Encode **state** entirely within the SYN-ACK sequence number



SYN
Seq = x



SYN-ACK
Seq =  , Ack = x + 1

 = HMAC of *(IP / port / seq)* w/ secret key

ACK
Seq = x + 1, Ack =  + 1

Server validates 

then saves **state** here

SYN Cookies

- General security strategy: rather than holding state, encode it so that it is still "trustable" when it's returned
  - Attacker now needs to *complete* 3-way handshake in order to burden server *(why is this okay?)*

Last Remarks

- Some remarks:
  - You need enough bits to encode all the state (just barely enough for
    HMAC is really great for this though—use a truncated HMAC
    Using b bits of HMAC ensures $\Pr[H_k(x) = H_k(y)] = 0.5^b$, so hash collisions are rare (in practice $b = 24$; remaining 8 bits are TCP boilerplate)
  - If it's expensive to create or validate cookie, then it's not good
    Digital signatures would be expensive—more resource exhaustion
    Once again, HMAC is really great for this
- Key idea: you can force others to store all the data you want, as long as you make sure to verify it later
  - Make sure to remember this! You'll see this later in the course…
- **TCP Cookie Transactions** (TCPCT) and **TCP Fast Open are** other approaches to mitigate syn flooding

More on scanning

Large-scale port scanning

- Can reveal lots of open/insecure systems!
- Examples:
  - shodan.io
  - VNC roulette
  - Open webcam viewers..
  - …
- Also: penetration testing/vulnerability scanning (more on this later)

Disclaimer

- Network scanning is easy to detect
- Unless you are the owner of the network, it's seen as malicious activity
- If you scan the whole Internet, the whole Internet will get mad at you (unless done very politely)
- Do NOT try this on the Brown network. I warned you.

Scanning I have done

- Scanned IPv4 space for ROS (Robot Operating System)
- Found ~200 “things” using ROS (some robots, some other stuff)